CHEMICAL ESSAYS

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tion

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ESSAY I.

OF BITUMENS AND CHARCOAL.

THE analyses of pitcoal and of different woods, mentioned in the last Essay, may serve as instances of the products obtainable by distillation from bituminous and vegetable substances in general. They all of them yield water impregnated with an acid, and often also with a volatile alkaline salt, air, oils of different colours, weights, and consistences, and a black coaly residuum. The bitumens generally taken notice

of by writers on Natural Hiſtory are, with reſpect to their conſiſtence, either as fluid as oil, or as thick and tenacious as tar, or quite ſolid. The fluid bitumens are two, *Naptha*, and *Petroleum*, or rock-oil. Theſe are oils which differ from each other in colour and conſiſtence, and ſome other properties; the naptha is pale, light, and very inflammable; the petroleum is yellow, brown, or blackiſh, heavier and leſs inflammable than naptha: its difference from naptha is attributed to its containing a greater quantity of acid in its compoſition. Both theſe oils are found in many parts of the globe, either floating on ſpring water, or dripping from the crevices of rocks. *Mineral pitch* is a bitumen which differs from petroleum in being thicker, heavier,

and more glutinous; it was formerly found in the environs of Babylon, and conſtituted, according to Vitruvius, when mixed with lime, the cement which was uſed in building the walls of that city. At preſent it is met with in ſeveral parts of Europe, and in America, where it drips from rocks, and is called by us *Barbadoes tar*: it has a very offenſive ſmell, and great tenacity, and is called by the inhabitants of Auvergne, in France, where it exudes from the earth, and ſticks to the feet, devils durg. The *Aſphaltum*, or *Jews pitch*, is a bitumen much reſembling mineral pitch; it is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah ſtood, otherwiſe called the *Dead Sea*, or the lake *Aſphaltes*, from a Greek word

 denoting

denoting a bitumen. This lake in the time of Esdras yielded Bitumen—*remember what I did to Sodom and Gomorrah, whose land lieth in clods of pitch**. The bitumen floating upon the surface of the salt water, is condensed by the heat of the sun into a solid form, and is gathered by the Arabs on the shore where it is thrown. It is said to be the same substance which the Egyptians used in embalming their mummies, and it was called by them *mumia mineralis*.† This bitumen has been found in many places of Asia and Europe, as well as on the shores of the Dead Sea; all that we meet with in the shops, is either an artificial composition, or an European asphaltum, the Eastern ones being seldom brought into Europe, but used

* Esd. B. 2. c. 2.
† Hasselquist's Voy. p. 285.

uſed by the natives either as pitch for their ſhips, or as an ingredient in varniſhing, or dying wool.

There is a very curious experiment which illuſtrates the relation which theſe four bitumens bear to each other. The moſt tranſparent oil of turpentine, reſembling naptha, may be changed into an oil reſembling petroleum, by mixing it with a ſmall portion of the acid of vitriol; with a larger proportion of the acid, the mixture becomes black and tenacious, like Barbadoes tar; and the proportions of the ingredients may be ſo adjuſted, that the mixture will acquire a ſolid conſiſtence, like aſphaltum. This experiment teaches us to conclude that naptha, petroleum, Barbadoes tar, and aſphaltum, differ chiefly from

each other, with respect to the quantity of acid which enters into their composition; and the substances procured by distilling pitcoal, or resinous vegetables, may furnish no improbable conjecture concerning the origin of these bitumens.

Let us suppose then a subterraneous fire to be situated in or near a stratum of pitcoal, of turf, of fossil wood, or of any other such bituminous matter; it is manifest that the inflammable air, and the different kinds of oils, which were collected by distilling small portions of these substances, would be elevated by the heat into the crevices of the superincumbent strata; the light and pale oil would be a sort of naptha, or petroleum, the black and tenacious oil would be a Barbadoes tar,

and

and this might be ſo dried by the heat as to become an aſphaltum. The oils not being miſcible with water, would be found floating upon its ſurface, as it iſſued out of the bowels of the earth, and being very inflammable, might conſtitute burning wells, ſuch as have been met with near Wigan, at Broſely, and in many other places: or where the oil did not meet with water, or was too heavy to float on it, we may conceive that it would impregnate the porous ſtrata of ſeveral kinds of ſtones and earth. It has been obſerved in another place,* that they formerly obtained a ſort of tar, from a ſtone at Broſely; and the ſtratum, which is called *ſhale* in Derbyſhire, is ſo ſtrongly impregnated with oil, that it will burn

* Vol. II. p. 347.

of itſelf, when ſet on fire: the workmen in digging through the black ſtone, which is incumbent on the ſhale, ſometimes meet with cavities containing a thick black oil, which has oozed out of the ſurrounding ſtone. One of the greateſt *ſoughs*, or ſubterraneous paſſages, which has, perhaps, ever been formed in Great Britain, is that which is called Hell-car ſough, in Derbyſhire; this ſough is driven through a ſtratum of ſhale, and the workmen are much troubled with inflammable air, which generally breaks into the ſough, through the ſame crannies which give paſſage to little ſtreams of water: they ſecure themſelves from the air, by keeping great fans conſtantly in motion; for the inflammable air, being lighter than common air, floats near the roof

of

of the fough, and being drawn down from thence, and mixed with the common air by the motion of the fans, it is circulated in the fough without danger. I am fenfible that inflammable air may be produced by various other ways, as well as by the application of heat, to bituminous ftrata; but as bitumens do yield inflammable air by diftillation, it is probable enough, that fuch as is met with in bituminous ftrata, may fometimes, at leaft, be referred to the action of a fire, fituated, perhaps, at too great a diftance from the furface of the earth, to produce any other fenfible effect.

In the Duchy of *Modena* in Italy, there is a remarkable rock, which confirms very much the notion of oils and pitchy fubftances being feparated

parated from bitumens by a kind of subterraneous diſtillation. The inhabitants of the diſtrict, by piercing the ſides of this rock, at different diſtances from its ſummit, obtain oils of different natures, thickening and growing heavier and deeper coloured, as the canals through which they flow approach to the ſurface of the earth; at the diſtance of a few feet below the ſurface, they find a very thick oil, which in digging deeper becomes ſoft as butter, and at ſtill a greater depth, it is found to be as ſolid as pitch.

Beſides *pitcoal* and *aſphaltum*, there are three other ſolid bitumens which deſerve to be mentioned—*Jet*—*Amber*—*Ambergris*. Jet ſo much reſembles cannel-coal in its colour, in its hardneſs, in its receiving a poliſh,

polish, in its not soiling the fingers when rubbed upon it, and in other properties, that many authors confound the two substances together; and indeed they agree in so many qualities that it is somewhat difficult to say in what they disagree. Jet, however, when warmed by friction, has the property of attracting bits of straw, feathers, and other light bodies; but I never observed this property in any of the cannel-coals which I have tried. This property, if it may be generally relied on, as appertaining to jet, and not to cannel-coal, is a very easy characteristic, by which these substances may be distinguished from each other. Jet is said to be found only in small detached pieces, and that it is thereby distinguishable from cannel-coal,

which

which is found in large beds. Some think that the woody fibrous tiſſue of jet, may ſerve to diſtinguiſh it from cannel-coal, but whoever examines large quantities of this kind of coal, will ſee many pieces which much reſemble wood in texture. The weight of a cubic foot of cannel-coal is 1273 ounces; a cubic foot of jet is ſaid by one author to weigh 1238,* by another 1185 ounces †

The natural hiſtory of *Amber* is very obſcure. This bitumen was for a long time thought to be reſtricted to the coaſts of Pruſſia, on the Baltic Sea. It was ſuppoſed to owe its origin to the exudations of certain trees on the coaſt of Sweden, which falling into the ſea, were there hardened by the continual action of

* Martin. † Lewis, Newm. Chem.

the ſalts, and thence carried by particular winds to the open coaſts of Pruſſia. This opinion was ſupported by, and formed to account for, the ants, flies, ſpiders, leaves of trees, and other terreſtrial matters, which are almoſt always found incloſed in pieces of amber, and which no doubt muſt be admitted, as proving its being originally in a fluid ſtate. In Pruſſia they not only gather amber on the ſea coaſt, but they frequently find it at the depth of eight or ten feet beneath the ſurface of the earth, but at no great diſtance from the ſea. The ſuperincumbent ſtrata are ſand, clay, foſſil-wood, pyrites, ſand again, in which the amber is found, ſometimes in detached pieces, ſometimes in little heaps. This diſtribution of the ſtrata, where amber is found, together

gether with their proximity to the ſea, has made it with ſome degree of probability be imagined, that this mineral owed its ſituation to the inundation and receſſion of the ſea, and that it was derived partly from an oil ariſing from the decompoſition of vegetables by ſubterraneous fires, and partly from a mineral acid. Amber is frequently found in Italy, where they have no foſſil-wood, but great plenty of petroleum.

The natural hiſtory of *Ambergris* is as uncertain as that of amber, unleſs we admit the deſcription which has been lately given of its origin, as the true one. We are told that ambergris is a part of the *Cachalot* or *Spermaceti-whale*. "It is found in this animal, in the place where the ſeminal veſſels are uſually ſituated in other animals.

It

It is found in a bag of three or four feet long, in round lumps, from one to twenty pounds weight, floating in a fluid rather thinner than oil, and of a yellowiſh colour. There are never ſeen more than four at a time in one of theſe bags; and that which weighed twenty pounds, and which was the largeſt ever ſeen, was found ſingle. Theſe balls of ambergris are not found in all fiſhes of this kind, but chiefly in the oldeſt and ſtrongeſt.*" This account ſeems probable enough, for ambergris is a fine perfume, and we know that other perfumes, ſuch as civet, muſk, and caſtor, are ſituated in the inguinal regions of the civet cat, the muſk animal and the beaver.

All vegetable, and bituminous, and

* Goldſmith's Nat. Hiſt. Vol. VI. p. 220.

and indeed all animal ſubſtances, leave, after their volatile principles have been ſeparated by diſtillation, a black coal. Theſe coals differ ſomewhat from each other, with reſpect to their proneneſs to catch fire, and their ability to ſupport it, but I will content myſelf with examining the nature of the reſidue, from the diſtillation of wood.

This reſidue does not differ from what is generally called charcoal; the ſlighteſt attention to the manner of obtaining this reſidue, and of making charcoal, will convince us, that no difference ought to be expected. When the wood is diſtilled, its communication with the external air is obſtructed, its volatile parts are elevated from it, by the heat to which it is expoſed, and the reſidue is that

part

part of the wood which remains after all the volatile parts are driven off. In making charcoal they conſtruct a pile of wood upon the ſurface of the ground, they cover the pile with a coating of turf, or other ſubſtances, and make the coating ſo compact, that it will not admit of air, except through ſome little round holes, which are purpoſely made in it, and which can be ſtopped at pleaſure. When the pile, thus conſtructed, is ſet on fire, part of the oil of the wood is conſumed during the burning of the pile, the other part, together with the air and water contained in the wood, is evaporated, and there remains, when the operation is finiſhed, the earthy part of the wood, called in that ſtate charcoal. Thus the making of charcoal

is a kind of diſtillation, for the coating which ſurrounds the pile of wood, may be compared to a retort.

Henckel informs us, that 150lbs. of oak, will produce 62lbs. of charcoal*; but he does not inform us whether the oak was dry or green, whether it had its bark on or was peeled, whether it was all heart of oak, or partly heart, and partly ſap, whether the operation of making the charcoal was diſcontinued as ſoon as the wood ceaſed to ſmoke, or protracted ſome time longer; and yet a difference in any one of theſe circumſtances, will ſenſibly influence the weight of the charcoal, procurable from a definite weight of wood.

The woods which I converted into charcoal were dry, and had been fel-

1 led

* For. Satur. c. iv. p. 55.

led many years; their relative weights were taken with great exactneſs.

Weight of a cubic foot of

Water	—	1000	avoir. ounces.
Box	—	950	——
Oak	—	892	——
Aſh	—	832	——
Mahogany	—	816	——
Walnut	—	790	——
Deal	—	615	——

Authors differ very much as to the weights which they have aſſigned to definite bulks of the ſame kind of wood. Thus, one eſtimates the weight of a cubit foot of dry box at 1030*; another at 1201 ounces†: one puts the weight of a cubic foot of dry oak at 925‡; another at 800 ounces||. To the more obvious

 ſources

* Cotes Hydroſ. p 73. † Ferguſon's Tab. p. 237. ‡ Cotes. || Emerſon's Mech. p. 132.

ſources of this diverſity, in the weights of equal bulks of the ſame kind of wood,—ſuch as the wood being green or dry, being cut from the boll or branch of a tree,—one may be added, which has not, I believe, been ſufficiently attended to —I mean the great loſs of weight which in certain circumſtances, the ſame piece of wood ſuſtains, by a ſimple expoſure to the atmoſphere, in the courſe of a few days.

From the middle of a branch of an oak tree, which had been felled in April, and expoſed without its bark, to the hot ſummer of 1779, I cut Sept. 4, a round piece, about ſix inches in diameter, and three in thickneſs: Sept. 15, I cut from the heart of this piece of oak a ſmall ſlip, 3 inches in length, $\frac{1}{4}$ of an inch in

thicknefs, and 79 grains in weight; at the fame time, I cut a fimilar flip from the fap of the fame piece, the weight of which alfo was 79 grains: thefe two pieces were put into the drawer of my ftudy table, and being weighed again, Sept. 25, the heart of oak had loft 8 grains, or near $\frac{1}{10}$ of its weight; the fap had loft 12 grains, or above $\frac{1}{7}$ of its weight. Now if the weights of feveral equal bulks of thefe woods had been taken on the 15th, and on the 25th of September, it is obvious (notwithftanding the contraction they might have fuffered) that there would have been fome difference in them, though the woods themfelves appeared equally dry on both days.

This fpeedy diminution of weight which wood undergoes by expofure

to the air, being a matter of ſome importance in an œconomical view, I will mention another experiment which I made on the ſubject. A piece of Aſh cut March 17, 1780, from the middle of a large tree, which had been felled ſix weeks before, was accurately weighed; its weight was 317 grains, its length 3 inches, and its breadth 2. It was weighed again March 24, it had loſt in the courſe of 7 days 62 grains, or near $\frac{1}{5}$ of its weight. I weighed this ſame piece of wood on the 25th of Auguſt in the ſame year, but it had not loſt any thing of its weight, from the 24th of March to the 25th of Auguſt. The two pieces of oak, mentioned in the laſt experiment, were weighed alſo, on the 25th of Auguſt, 1780; they had neither of

them

them loſt, in the courſe of eleven months, quite 1 grain; hence it appears, that the matter which is diſperſed from wood after it is cut, is ſoon evaporated: this matter probably conſiſts chiefly of water. The carriage of wood, eſpecially by land, is very expenſive: if an oak or an aſh tree was cut into boards, or ſcantlings, upon the ſpot where it is felled, there would be a ſaving of the carriage of one ton in ſix or ſeven from the evaporation of the ſubſtance of the wood; to ſay nothing of chips and other refuſe parts.

It is well known that all wood becomes heavier than water, by having the air extracted from the pores, either by an air-pump, or by boiling it in water. The woods of which I have given the relative weights,

were

were all of them rendered heavier than water, by a long continuance in cold water; for the heat of the water in which they were put, never exceeded 60 degrees. They ſunk in the water after they had been ſoaked in it for different lengths of time, but it required above 100 days ſoaking before the deal would ſink. After they had all lain in water for 110 days, I took them out, and let them dry by the gradual heat of the atmoſphere for above a month; I then weighed them, and found that box, oak, and aſh, had each of them loſt $\frac{1}{32}$ of the weight they had before they were put into the water; but that mahogany, walnut, and deal, had loſt only $\frac{1}{60}$ of their weight. This loſs of weight is occaſioned, partly by the eſcape of ſome portion

of

of air, and partly by a diſſolution of ſome of the other principles of the woods; for the water, in which they were placed, had evidently acted upon them, its colour and conſiſtence being both changed. Moſt woods contain both a *gummy* and a *reſinous* part; and gums being ſoluble, and reſins not ſoluble in water, we can have no difficulty in apprehending the reaſon, why ſome ſorts of wood loſe a greater proportion of their weight, by being immerſed in water, and afterwards dried, than others. Since the ſame piece of wood has very different weights, when dry and when ſoaked with water; the covering carts, ploughs, and other huſbandry gear, uſually made of aſh, with a coarſe kind of paint which will keep out the rain,

is a practice full as serviceable in lessening the weight of the implement which is to be moved by the strength of a man or a horse, as in preserving the wood of which it is made from decay.

I took square pieces of the woods before mentioned, each piece being 3 inches in length, and weighing exactly 96 grains, and exposed them, when covered with sand, in a crucible, to the action of the same fire, which was strong enough to keep the crucible red hot, for three hours; they were at the end of that time, all of them converted into perfect charcoals; the weights of the respective charcoals were taken, whilst they were still *warm*, from the operation, and are expressed in the following table:

Walnut	96 grs.	gave	25 grs.	of charcoal.
Oak —	96	— —	22	——
Box —	96	— —	20	——
Mahogany	96	— —	20	——
Aſh —	96	— —	17	——
Deal —	96	— —	15	——

There is a good reaſon for remarking, that the charcoals were weighed whilſt they were warm, for in weighing them a few days afterwards, I found that they had all increaſed in weight in conſequence of *ſomething* which they had attracted from the atmoſphere: their weights then were —walnut 26—oak 24—box 23—mahogany 24—aſh 18—deal 16—grains.

The quantities of reſidue remaining from the diſtillation of 96 ounces of oak, box, and mahogany, were reſpectively 30, 26½, and 27½ ounces,

ounces, which numbers are ſeverally larger than thoſe, expreſſing the quantities of charcoal obtainable from 96 parts of thoſe woods; this difference may proceed from the woods, employed in the two proceſſes, being of different qualities, or, more probably, from the heat in which the charcoal was made, being greater than that employed in the diſtillation; for the ſtronger the fire, the leſs is the quantity of charcoal, which a definite weight of wood will yield.

In making charcoal the workmen obſerve, that the pile of wood is ſenſibly diminiſhed in ſize by the operation; this proceeds from the ſhrinking of the wood. All the kinds of wood which I charred were diminiſhed in all their dimenſions,

the mahogany, oak, and walnut, were the leaſt diminiſhed; and the box was the moſt diminiſhed; I thought it had loſt an eighth part of its length. This diminution not only depends upon the nature of the wood, but it is influenced by the ſtrength and continuance of the heat, that being moſt diminiſhed, which has ſuſtained the greateſt heat.

Though charcoal, from every ſort of wood, is incapable of being decompoſed, by the ſtrongeſt fires in cloſe veſſels, yet it is a compounded body, and may be decompoſed by being burned in the open air.

Van Helmont ſays, that 62 pounds of oak charcoal will, by burning, yield only 1 lb. of white aſhes. The other 61 pounds which are diſperſed into the air, he conſiders as a vapour

of an elastic nature, which can neither be collected in vessels, nor reduced into a visible form. This vapour he called by a new name, *gas**.

Stahl is of opinion, that 10 lbs. of charcoal made from porous woods, such as fir and sallow, will not when burned with a very slow fire, yield above 1 lb. of ashes†; this quantity however, it must be remarked, is above six times the quantity assigned by Van Helmont to oak which probably contains more ashes in a definitive weight of charcoal, than either fir or sallow.

Geoffroy,

* Hunc spiritum, incognitum hactenus, novo nomine gas, voco, qui nec vasis cogi nec in corpus visibile reduci potest. Van Hel. Op. omn. p. 193. Some derive gas from the Dutch ghoast-spirit; others from the German gascht, a frothy ebullition.

† Stahlii Exper. Numero CCC. p. 17.

Geoffroy, from ſomewhat leſs than 34 ounces of the charcoal, remaining after the diſtillation of the heart of guaiacum, got near three ounces of white aſhes, by calcining the coal in an open fire for 12 hours. From near 23½ ounces of the coal, remaining from the diſtillation of the ſap of guaiacum, he got near 1½ ounce of aſhes. And 29½ ounces of the coal, from the bark of guaiacum, gave him 13½ ounces of white aſhes*.

Laſtly, Mr. Sage aſſures us that 100 pounds of charcoal will not, when burned, furniſh quite 2 ounces of aſhes†.

Theſe accounts, it muſt be ac-know-

* Geoff. Mat. Med. or treatiſe on foreign vegeta. by Thickneſs, p. 112.

† Exper. ſur. l' Alk. Vol. fluor. p. 27.

knowledged, differ very much, as to the quantity of aſhes obtainable from a definite weight of charcoal; and the difference, I think, is much greater than what can wholly be attributed to the different textures of the ſeveral woods; a part of this diverſity may, probably, ariſe from a difference in the manner of burning the charcoal. When charcoal is burned in ſmall quantities, and in a ſlow fire, leſs of its ſubſtance will be diſperſed into the air, than when the quantity is larger, and the ſtream of air which ſupports the fire, is more rapid. This ſeems not improbable; but if the weight of the aſhes remaining from the burning of a definite weight of charcoal, be at all influenced by the degree of fire, it ſeems reaſonable to ſuppoſe, that

what

what is driven off by the violence of the fire, is of the ſame earthy nature as that which remains when the fire is more moderate; at leaſt it may be argued, that when charcoal is burned with a ſlow fire, ſome of its principles, its oily principle for inſtance, though it, probably, alſo contains a ſaline one, are more completely decompoſed, than when it is conſumed with a violent fire, and that the decompoſition of theſe principles gives an additional quantity of earth or ſalt to the aſhes.

If there be any truth in this notion, we muſt not ſay, that the 61 pounds of matter which, according to Van Helmont, are diſperſed into the air from 62 pounds of charcoal, are wholly of an elaſtic nature; ſince they may conſiſt principally of an

attenuated earth, which being driven off by the current of air, requiſite for the maintenance of the fire, remains for a time ſuſpended in the atmoſpherical air, without being in its own nature elaſtic. I would not be underſtood to ſay, that the whole of what is diſſipated, during the burning of the charcoal, is an attenuated earth, ſince it is certain, that the earth of the aſhes is not inflammable, and that charcoal contains ſomething which is inflammable: it is allowed alſo, that ſimple earth is inodorous: and it is well* known that charcoal, during its inflammation, diſperſes ſomething into the air, which has a ſtrong ſmell; this *ſomething* by which charcoal is rendered inflammable, and by which the air is infected with a particular ſmell, during the burning

ing of the charcoal, is called by most chemists the phlogiston*. This phlogiston,

* Phlogiston is a constituent part of metallic substances, and it seems, when separated from them, to be of an elastic nature. I distilled zinc with *strong* acid of vitriol, and obtained a portion of sulphur, produced as it should seem, by the acid's uniting itself with the phlogiston of the zinc. No inflammable vapour was produced, till the sulphur began to be sublimed; then, indeed, there escaped a vapour, composed, I think, of the attenuated parts of sulphur, which upon the approach of a candle took fire. Another portion of zinc was distilled with *weak* acid of vitriol; before the zinc felt the heat of the fire, the inflammable air, separable from zinc by a weak acid of vitriol, passed into the receiver, and being set on fire, burst it with a great explosion: another receiver was applied, and the distillation continued to dryness, but not a particle of sulphur was produced, the phlogiston necessary for its formation having, probably, been separated from the zinc, by the violent action of the

I

phlogiston, whether it be an elastic inflammable fluid, or an unelastic earth of a particular kind, constitutes, probably, but a very small portion of the weight of what is dispersed into the air, from burning charcoal: we all know what a strong smell may be diffused through a large room, from the ignited snuff of a candle, or from a very small piece of charcoal, which has not been thoroughly burned; the vapours issuing from these substances are of an oily saline nature, and are visible: the vapour of charcoal, though it is too subtle to be seen, may be of a nature somewhat similar, and capable

acid, and consumed at once by the inflammation. May it not, from the comparison of these experiments, be conjectured, that the phlogiston of metals is an elastic inflamma-

ble of a very extenſive diffuſion through the air. An infant has been known ſuddenly to expire, from the ſmoke of a candle blown out under its noſe, and the vapour of charcoal is moſt dangerous, when the charcoal has not been thoroughly burnt.

It has been found by experiment, that the common atmoſpherical air is much altered in its properties, by being made to paſs through red hot charcoal, into the vacuum of an air-pump; it then extinguiſhes the flame of a candle, and animals die in it*. A ſimilar change takes place, when charcoal is conſumed in an apartment, which has not a ſufficient ſupply of freſh air; the inſtances of perſons who have unhappily loſt their lives in ſuch air, are very common in

* Haukſbee's Exper. p. 287.

all countries, where much uſe is made of charcoal; but eſpecially in Ruſſia, where their apartments are heated by ovens, containing red hot charcoal*. The change which the atmoſpherical air undergoes, from the burning of charcoal, may proceed either from the air, having loſt ſome of its conſtituent parts in coming in contact with the burning charcoal, or from its having gained ſomething from the charcoal, or from its having done both at the ſame time; juſt as water, which paſſes through a lump of ſalt or ſugar, loſes a great

* Philoſ. Tranſ. 1779, p. 325—Where there is mention made of the Ruſſian method of recovering perſons who have been rendered ſenſeleſs by the vapour of the charcoal; it conſiſts in carrying the perſon into the open air, rubbing him with ſnow or cold water, and pouring water or milk down his throat.

a great part of the air it contains in its natural ſtate, and gains a portion of the ſalt, which becomes diſſolved in it, and upon both accounts ſuffers a change of its properties.

It is generally admitted, that charcoal and all other bodies, nitrous ones excepted, ceaſe to burn, as ſoon as they ceaſe to be ſupplied with freſh air, and the air has, chiefly on this account, been thought to communicate ſomething to the fire, by which the fire was maintained, and the air was conſumed. And this opinion has been confirmed by obſerving, that a definite quantity of air was much diminiſhed in bulk by bodies being burned in it. Thus, if 10 cubic inches of air be made to paſs through red hot charcoal, they will be reduced to nine, and there

are means of making the diminution ftill greater.

Dr. Hooke advances another hypothefis; he allows air to be neceffary to the fupport of fire, but he thinks that it contributes to this fupport, not by imparting any thing of its own fubftance to the fire, but by *diffolving* the inflammable principle of bodies, as water diffolves falts*: according to the former hypothefis, air is the *food*; according to this, it is the *receptacle* or *folvent* of fire.

Dr. Prieftley, to whofe inventive genius and indefatigable induftry the philo-

* Hooke's Micogr. p. 103. and Pofthum. Works, p. 169. Juncker feems to have entertained a fimilar notion—ingens aeris quantitas requiritur ad *diffolvendas* et recipiendas ignitas illas et ultimo motu attenuatas particulas, unde nifi fat aeris fit extinguitur ignis. Junck. Conf. Chem. Vol. I. p. 157.

philosophic world is peculiarly indebted for his inquiries into the nature of fictitious airs, has observed, that common air is diminished one fifth by the fumes of burning charcoal; and this diminution, he thinks, is some how or other effected by the air being highly charged with the phlogiston of the charcoal; and he observes, which agrees very well with Dr. Hooke's hypothesis, that when any definite quantity of air is fully saturated with phlogiston from charcoal, no heat that he had ever applied was able to produce any more effect upon the charcoal*.

Though common air is diminished in bulk by the fumes of burning charcoal, and of other bodies in a state of combustion, yet a bottle or a bladder filled

* Philos. Trans. 1772, p. 225—230.

filled with this diminiſhed air, weighs leſs than when it is filled with common air*, in the proportion of 183 to 185. That 5 cubic inches of common air ſhould be reduced by the fumes of burning charcoal to 4 cubic inches, and that theſe 4 cubic inches of infected air ſhould weigh leſs than 4 cubic inches of common air, cannot well be accounted for without admitting, that a part of the 5 cubic inches of atmoſpherical air has been, by ſome means or other, taken away, at the ſame time that its bulk was reduced to 4 cubic inches.

Being deſirous of ſeeing, whether the property I had obſerved in charcoal, with reſpect to its weighing leſs when it was quite cold, than when it was warm from the fire in which it

* Prieſt. Exp. and Ob. Vol. II. p. 94.

it had been made, was a general property appertaining to all hot and cold charcoal, I weighed ſeveral pieces when they were cold, and again, when they were ſo hot as to be handled with difficulty, and found that they all loſt (they were of the ſame kind of wood) about 1 part in 12 of their weight, and that being left to cool in the open air, they regained what they had loſt in a few days. This acquiſition of weight was made moſt rapidly at firſt: a piece which weighed 240 grains when cold, was reduced by being heated, to 220 grains, and being left to cool, it gained 9 grains in 4 hours, and 15 grains in 8 hours. From the manner in which charcoal is made, it is probable that what remains adherent to the wood, is not greatly

different

different from what is forced from it by the laſt degree of heat; now this conſiſts of an acid, and an oil rendered thick and pitchy by its union with an acid; may we not hence ſuppoſe, that it is a portion of fixed acid, which attracts the humidity of the air, or perhaps the air itſelf, when the charcoal is hot, and becomes ſaturated therewith, and that what was attracted is again driven off, when the charcoal is again heated; and thus the charcoal becomes again capable of exerting its attraction, and acquiring an increaſe of weight? It is ſome confirmation of this hypotheſis, that charcoal, when taken out of hot ſand, takes fire upon expoſure to the air, and for much the ſame reaſon, probably, that Homberg's pyrophorus takes

fire

fire in the open air*. Guaiacum contains a ſtronger acid than moſt kinds of wood; and Geoffroy has obſerved, that "the coal of guaiacum being taken out of the retort, and expoſed to the air, even two or three days after the proceſs, takes fire immediately of its own accord;

pro-

* Homberg's Pyrophorus is known to every ſchool-boy. It is made by calcining together for a proper time, and in proper quantities, either alum or any ſalt containing the vitriolic acid, with honey, ſugar, flour, or any animal or vegetable ſubſtance, capable of being reduced to a coal. Part of the vitriolic acid being uncombined with the phlogiſton of the coal, and being in a dry condenſed ſtate, attracts the humidity of the atmoſphere, and generates ſuch a degree of heat by its mixture with water, as is ſufficient to inflame the other part of the pyrophorus. Pyrophori may be made without the vitriolic acid, but ſome acid probably enters into their compoſition.

provided, that when the diſtillation is over, the neck of the retort be carefully ſtopped, and the veſſels and furnace be left to cool of themſelves*."

This property of increaſing in weight by expoſure to the air, belongs to the hot coal of pitcoal, as well as to that of wood. I took ſome red hot cinders, and weighing them in that ſtate, left them to cool; in 12 hours they had gained one 75th part in weight, and in 4 days they had gained one thirtieth of their weight. Some coak which had been burned with a ſtrong fire, gained much leſs than the cinders.

It has been obſerved in another place, that charcoal may be decompoſed, by being diſtilled with the acid

* Treatiſe on Foreign Veget. p. 111.

acid of vitriol*; this acid robs the charcoal of its inflammable principle, and reduces it to an earth: no other menſtruum ſeems to have any action upon it. What alteration might be produced in charcoal, by quenching it when red hot, in various menſtruums, or by boiling it in them, or by keeping it immerſed in them, when cold, for a long time, or by other leſs obvious proceſſes, it does not fall within my deſign to inquire.

Animals and vegetables are ſoon reduced by putrefaction to an earth; many ſorts of ſtones and metallic ſubſtances are crumbled into duſt by the action of air and water; but charcoal remains unchanged for ages, whether it be expoſed to the air, or immerſed in water, or buried in the earth. The beams of the theatre at

* Vol. I. p. 175.

at *Herculaneum* were converted into charcoal by the *Lava*, which overflowed that city; and during the lapſe of above ſeventeen centuries the charcoal has remained as intire as if it had been formed but yeſterday, and it will probably continue ſo to the end of the world. This incorruptibility, as it may be called, of charcoal, has been known in the moſt diſtant ages; for it has been obſerved, that the famous temple of Epheſus was built upon wooden piles which had been charred on the outſide. The cuſtom of charring the ends of poſts, which are to be fixed in the earth, is very common; and I have often wondered that the ſame cuſtom has not prevailed with reſpect to the wood uſed in mines and ſubterraneous drains. The timbers

bers which ſupport, in many places, the roof of the ſoughs through which there is a current of water, are waſted away in a few years, that part of them eſpecially which is expoſed to the alternatives of moiſture and dryneſs by the riſing and falling of the water is ſoon rotted, and this part one would think would be charred with great advantage.

ESSAY II.

OF THE QUANTITY OF WATER EVAPORATED FROM THE SURFACE OF THE EARTH IN HOT WEATHER.

THERE are many operations conſtantly carrying on by natural means, which, though they eſcape the ordinary obſervation of our ſenſes, ſufficiently excite our aſtoniſhment, when once diſcovered. The vaſt quantity of a particular kind of air, with which the atmoſphere is daily impregnated, from the combuſtion of all ſorts of fuel, is

 one

one inſtance of this kind; and the water which is raiſed into the atmoſphere from the ſurface of the earth, is another. Who would have conjectured, that an acre of ground, even after having been parched by the heat of the ſun in ſummer, diſperſed into the air above 1600 gallons of water in the ſpace of twelve of the hotteſt hours of the day? No vapour is ſeen to aſcend, and we little ſuppoſe that in the hotteſt part of the day, more uſually does aſcend than in any other. The experiment from which I draw this concluſion, is ſo eaſy to be made, that every one may ſatisfy himſelf of the truth of it. On the 2d of June, 1779, when the ſun ſhone bright and hot, I put a large drinking glaſs, with its mouth downwards, upon a graſs-plat which

was mown close; there had been no rain for above a month, and the grass was become brown; in less than two minutes the inside of the glass was clouded with a vapour, and in half an hour drops of water began to trickle down its inside, in various places. This experiment was repeated several times with the same success.

That I might accurately estimate the quantity, thus raised, in any certain portion of time, I measured the area of the mouth of the glass, and found it to be 20 square inches: there are 1296 square inches in a square yard, and 4840 square yards in a statute acre; hence, if we can find the means of measuring the quantity of vapour raised from 20 square inches of earth, suppose in

 one

one quarter of an hour, it will be an easy matter to calculate the quantity which would be raised with the same degree of heat, from an acre in 12 hours. The method I took to measure the quantity of vapour, was not perhaps the most accurate which might be thought of, but it was simple and easy to be practised: when the glass had stood on the grass plat one quarter of an hour, and had collected a quantity of vapour, I wiped its inside with a piece of muslin, the weight of which had been previously taken; as soon as the glass was wiped dry, the muslin was weighed again, its increase of weight shewed the quantity of vapour which had been collected. The medium increase of weight, from several experiments made on the same day,

between

between 12 and 3 o'clock, was 6 grains collected in one quarter of an hour, from 20 ſquare inches of earth. If the reader takes the trouble to make the calculation, he will find that above 1600 gallons, reckoning 8 pints to a gallon, and eſtimating the weight of a pint of water at one pound avoirdupois, or 7000 grains troy weight, would be raiſed, at the rate here mentioned, from an acre of ground in 24 hours.

It may eaſily be conceived, that the quantity thus elevated will be greater when the ground has been well ſoaked with rain, provided the heat be the ſame; I did not happen to mark the heat of the ground when I made the fore-mentioned experiments; the two following are more circumſtantial: the ground had been

wetted the day before I made them by a thunder ſhower, the heat of the earth, at the time of making them, eſtimated by a thermometer laid on the graſs, was 96 degrees; one experiment gave 1973 gallons from an acre in 12 hours, the other gave 1905. Another experiment made, when there had been no rain for a week, and the heat of the earth was 110 degrees, gave after the rate of 2800 gallons from an acre in 12 hours; the earth was hotter than the air, as it was expoſed to the reflection of the ſun's rays from a brick wall.

The heat in *Bengal* in the ſummer months is variable, in the ſhade from 98 to 120 degrees*, and in the ſun it probably does not fall ſhort of

140

* Philoſ. Tranſ. 1767, page 218, and for the year 1775, p. 202.

140 degrees; hence, after the earth has been well drenched by the overflowing of the *Ganges*, immenſe quantities of vapours muſt be daily raiſed, to the amount, perhaps, of five or ſix thouſand gallons from an acre, in twenty-four hours. The rainy ſeaſon in Bengal laſts from the beginning of June to the middle of October; all this interval is conſidered as an unhealthy time, but eſpecially the latter part of it, for then the earth begins to grow dry, the ſlime left upon its ſurface, conſiſting of decayed vegetables and other putreſcent bodies, begins to corrupt; and the ſun, by its violent and continued action, raiſes up into the air not a pure water, but water impregnated with putrid particles of all kinds.

Whether a merely moiſt ſituation

be

be unwholeſome, may be much queſtioned; but that moiſture ariſing from earth or water in a ſtate of putrefaction is ſo, cannot well be doubted. The overflowing of the *Nile* puts a ſtop to the plague in *Egypt*, inſomuch, probably, as it puts a ſtop to the putrefaction of the canals of *Grand Cairo* and other places. Agues and putrid fevers are much more frequent in the fens of *Cambridgeſhire* and *Lincolnſhire* in very dry, than in wet years; the *Iriſh*, who annually come to reap the harveſt in the fens of Cambridgeſhire, have been ſo ſenſible of the difference, that for the three or four years laſt paſt, which have been very dry, they have entered upon their taſk with great reluctance, and apprehenſion of what they call the *Fen-ſhake*: The

States

States of *Holland*, in the year 1748, laid the country around *Breda* under water, and ordered the water to be kept up till the winter, in order to ſtop a ſickneſs which had ariſen from the moiſt and putrid exhalations of half-drained grounds.* The *Arabs* are ſaid to take a horrid kind of vengeance when they think themſelves injured by the *Turks* at *Baſſora*; they contrive to overflow the adjoining country: a peſtilential fever begins to ſhew itſelf as the land begins to grow dry by the evaporation of the water, and it rages with ſuch violence as to carry off many thouſands of the inhabitants of that city †.

The nature of the ſoil muſt have a great influence on the health of the people

* Sir J. Pringle's Diſ. of the Army, p. 63.

† Philoſ. Tranſ. 1778, p. 215.

people who inhabit it, ſo far as that is dependent on the moiſture or dryneſs of the air. There is, probably, as much water raiſed into the air, in a hot day, from an acre of ground in the fens of *Cambridgeſhire*, as is raiſed in two or three days from an equal ſurface in the ſandy parts of *Norfolk* and *Suffolk*. Not but the moſt ſandy country may have a very moiſt atmoſphere, when water happens to be found near the ſurface; for the heat of the ſun will penetrate through the ſand, and raiſe the water in vapour, which will find an eaſier paſſage through the ſand than it would do through a leſs open ſoil. Thus the ſoil in ſome parts of *Dutch Brabant* is a barren ſand, but water is every where to be met with at the depth of two or three feet, and in propor-

proportion to its distance from the surface the inhabitants are free from diseases *.

Vegetation must be greatly influenced by the quantity of water which is raised from the earth; some soils retain humidity much longer than others, and one great use of marles and other manures, is, to render the soil on which they are put less liable to be deprived of its moisture by the heat of summer. The water, in ascending from the bosom of the earth, moistens the roots, and in being dissolved in the air, it affords nutriment to the branches of vegetables; but as vegetation may be injured either by a defect, or an excess of moisture, and as different plants require different quantities of it, for attaining their

* Diseas. of the Army, p. 62.

their utmoſt perfection, it merits the attentive obſervation of the farmer to ſuit his plants and his manures to the nature of the ſoil. There are many ſandy and limeſtone ſoils, which are covered almoſt with flints or limeſtone pebbles; the crop of corn would, probably, be leſs, if theſe ſtones were removed: for they are ſerviceable, not only in ſheltering the firſt germs of the plant from cutting winds, but they impede the eſcape of moiſture from the earth; the aſcending vapour ſtrikes upon that ſurface of the ſtone which is contiguous to the earth, and is thereby condenſed, and thus its further aſcent is for a time, at leaſt, prevented.

Upon the ſame graſs-plat, and contiguous to the glaſs uſed in the experiments, I placed a ſilver cup,

with

with its mouth downwards, of a ſhape ſimilar to that of the glaſs, and nearly of the ſame dimenſions; but I could never obſerve that its inſide had collected the leaſt particle of vapour, though I frequently let it ſtand on the graſs for half an hour, or more.

By means of a little bees wax, I faſtened an half crown very near, but not quite contiguous, to the ſide of the glaſs, and ſetting the glaſs, with its mouth downwards, on the graſs, it preſently became covered with vapour, except that part of it which was near to the half crown. Not only the half crown itſelf was free from vapour, but it had hindered any from ſettling on the glaſs which was near it, for there was a little ring of glaſs ſurrounding the half

crown to the diſtance of $\frac{1}{4}$ of an inch which was quite dry, as well as that part of the glaſs which was immediately under the half crown; it ſeemed as if the ſilver had repelled the water to that diſtance. A large red wafer had the ſame effect as the half crown; it was neither wetted itſelf, nor was the ring of glaſs contiguous to it wetted. A circle of white paper produced the ſame effect, ſo did ſeveral other ſubſtances, which it would be tedious to enumerate.

Theſe phenomena, reſpecting the different diſpoſitions of different bodies to attract the *riſing* vapour, are ſimilar to what others have taken notice of concerning the *falling* of dew, and are, probably, to be explained upon the ſame principles, whatever they may be. Muſchen-

broek

broek placed on the leaden terrace of the Obſervatory at Utrecht, veſſels of glaſs, china, varniſhed wood, poliſhed braſs, and pewter: he found that in the courſe of a night the glaſs, china, and varniſhed wood, had collected a great abundance of dew, but that not a drop had fallen on any of the poliſhed metals*. M. du Fay expoſed to the air, when the dew was falling, two large funnels, one made of glaſs, the other of poliſhed pewter; the necks of the funnels being inſerted into veſſels proper to retain any moiſture which might be collected by them; he ſometimes found in the morning that the veſſel under the glaſs funnel contained an ounce or more of water,

 but

* Introd. ad Philoſ. Nat. Tom. II. p. 990.

but he never obſerved ſo much as a drop in the other *.

A great part of the water which is raiſed into the air from the perſpiration of the earth during a hot day, deſcends down again upon its ſurface in the courſe of the night; and this is the reaſon that the dews are the greateſt in the hotteſt weather, and in the hotteſt climates. The earth retains the heat it receives in conſequence of the ſun's action longer than the air does; water, moreover, is evaporable in all degrees of heat; hence water may continue to riſe from the earth, when the air, being cooled by the abſence of the ſun, is no longer able to ſuſtain what is thus raiſed, or to retain what it

* Hiſt. de l'Acad. des Scien. 1749.

it had taken up during the day time; and a dew from these different causes may, under certain circumstances, be found both to rise and fall during the whole night.

Egypt, at one season of the year, is so parched up by the heat, that the surface of the ground becomes quite rugged with fissures; at this time the dew, proceeding from the vapour exhaled from the earth, is very plentiful, and by its plenty prevents the total destruction of the country. "This dew is particularly serviceable to the trees, which would otherwise never be able to resist the heat; but with this assistance they thrive very well, blossom and ripen their fruit. Therefore the upper parts of the Egyptian trees, at one time of the year, do the office of

 roots,

roots, attracting nourishment by their absorbent vessels, the leaves, from the moist air *.

The quantity of water which was condensed on the inside of the glass, I found to be accurately proportionable to the time during which it stood on the grass; for in one experiment 6 grains were collected in 10 minutes, and in another 15 grains were collected in 25 minutes; now the proportion of 6 to 10 is the same as that of 15 to 25.

In order to see whether the copious vapour collected by the glass was owing to the natural perspiration of the grass, or to a kind of mechanical distillation from the body of the earth, I put the glass upon a footpath which was dry, and had no grass

* Hasselquist's Voy. p. 455.

grafs growing upon it, the vapour rofe from the footpath as well as from the grafs, but not fo abundantly.

From what has been advanced, it may, probably, be juftly inferred, that the air contiguous to, or not far removed from, the furface of the earth, whether that furface be plain or mountainous, barren, or covered with vegetables, will be much more loaded with the vapour which arifes conftantly from the earth, than that which is at the diftance of even a few yards from the furface. This point may be illuftrated by the following hypothefis——Suppofe the earth to be a globe of rock falt, and to be covered with water to the height of a mile; imagine the water to be divided into four fpherical

 fhells,

ſhells, each $\frac{1}{4}$ of a mile in thickneſs. Now the firſt ſhell, which is ſuppoſed to be contiguous to the ſurface of the ſalt, would ſoon ſaturate itſelf with the ſalt, and becoming thereby heavier than the water at a greater diſtance, it would not, by the ordinary motion of the winds and tides, ſoon mix itſelf with the whole maſs of water; but it would contain far more ſalt in ſolution than the ſecond ſhell, and the ſecond would contain more than the third, and the third more than the fourth. Let us further ſuppoſe the ſalt contained in the whole of the water to be precipitated, and the precipitation to begin from the ſhell fartheſt removed from the ſurface of the earth; it is evident, that the quantity of the precipitate will increaſe,

 not

not ſimply with the increaſe of ſpace through which it has deſcended, but in a much higher proportion, inaſmuch as the laſt ſhell through which it deſcends may be ſuppoſed to contain three or four times as much ſalt as the uppermoſt. In like manner, it ſeems reaſonable to ſuppoſe that the air which is near the ſurface of the earth will be much more charged with water, which it diſſolves as water diſſolves ſalt, than that which is ſituated at the diſtance of even a few yards from the ſurface.

Dr. Heberden was the firſt perſon who took notice that a much larger quantity of rain falls into a rain-gage ſituated near the ſurface of the earth, than into one of the ſame dimenſions ſituated a few yards above

 it;

it*; and he thinks that this difference is to be explained from ſome unknown property of electricity. The fact is placed beyond controverſy, by experiments which have been made at various places; at Liverpool in particular it has been obſerved, that "a veſſel ſtanding on the ground in a ſpacious garden, received *double* the quantity of rain which fell into another veſſel of equal dimenſions placed near the ſame ſpot, but eighteen yards higher†." I am far from thinking that the foregoing obſervations relative to the quantities of water contained in

* Phil. Tranſ. 1769, p. 361.

† See an ingenious eſſay on the ſubject, by Dr. Percival, who has explained the phenomenon from the known principles of electricity. Eſſays by Dr. Percival, p. 112.

in equal bulks of air at different heights from the ſurface of the earth, contain a ſatisfactory explanation of this phenomenon; yet it may be remarked, that rain-gages placed at equal diſtances from the ſurface of the earth, collected nearly equal quantities of rain, though one of them was ſituated on a plain, and the other on a mountain 450 yards in height above the plain*: this obſervation is ſome confirmation of the hypotheſis which has been mentioned, as on that ſuppoſition it follows, that the air at the ſame diſtance from the ſurface of the earth, is equally impregnated with water, other circumſtances being the ſame, and therefore equal quantities of rain *ought* to be collected by veſſels

placed

* Philoſ. Tranſ. 1772, p. 294.

placed at equal diſtances from the ſurface of the earth; though according to the ſame ſuppoſition, a much larger quantity *ought* to be collected by a veſſel placed on the ſurface, than by one placed a few yards above it. Thus this hypotheſis, admitting its truth (which future experiments will perhaps eſtabliſh), ſeems as if it was ſufficient for explaining the phenomenon; I would be underſtood however to mention it with much diffidence, and was I as much ſkilled in electricity, as the very worthy and ingenious perſon, who firſt noticed the fact, is in every branch of natural philoſophy, I might probably have ſeen reaſon not to mention it at all.

ESSAY III.

OF WATER DISSOLVED IN AIR.

WE have ſeen, in the preceding Eſſay, that large quantities of water are raiſed from the earth in the hotteſt weather: the water, which is thus elevated, is no more viſible in the air, than a piece of ſugar is viſible in the water wherein it happens to be diſſolved, nor is the tranſparency of the air injured by the water it has received from the

earth;

earth; and therefore we conclude, that the water is not merely *mixed* with the air, but really *diſſolved* in it; a perfect tranſparency of the fluid, in which any body is diſſolved, being eſteemed the moſt unequivocal mark of its ſolution.

The cauſe of the aſcent, ſuſpenſion, and deſcent of vapours, is not yet fully determined; many think that electricity is the principal agent in producing theſe phenomena*; whilſt others are of opinion, that water is raiſed and ſuſpended in the air, much after the ſame manner in which ſalts are raiſed and ſuſpended in water; and it muſt be owned that this opinion

* Philoſ. Tranſ. 1755, p. 124.—Electricitas vapores in aërem extollit, in aëre ſuſpendit, et ex aëre in tellurem depluit. Prof. Bavers Exp. de Elec. Theo. p. 106.

opinion (which future experience may ſhew not to be wholly inconſiſtent with the other) has a great appearance of probability.

Salts, in general, are more ſpeedily diſſolved in warm water than in cold; and water, in like manner, is more ſpeedily diſſolved in warm air than in cold. We have a ſenſible proof of this in the exhalation of dew, it being much ſooner dried up in places expoſed to the direct rays of the ſun, than in the ſhade, becauſe the air in the ſhade being ſome degrees colder than that in the ſun, is not able to diſſolve the ſame quantity of water in the ſame time.

When water is ſaturated with any kind of ſalt in a definitive degree of heat, then will it retain the ſalt as long as it retains its heat; but if the

heat be lessened, the transparency of the solution will be destroyed, a part of the salt will become visible, and fall to the bottom, in consequence of its superior weight; what falls to the bottom will be re-dissolved, as soon as the water regains its heat. It is obvious that the quantity of the salt which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the solution is saturated, and partly on the degree of cold to which the solution is reduced. Thus water of 80 degrees when saturated with salt, contains more salt than it would do if it had only 70 degrees of heat, and in being cooled to 50 degrees, the precipitation of salt will be greater in the first instance, than in the second; though it might probably be

the

the ſame if the ſolution of 80 degrees was cooled only to 60, and that of 70 to 50. Something very analogous to all this may be obſerved with reſpect to the ſolution of water in air. In miſty weather we frequently ſee the miſt of the morning intirely vaniſhing towards the middle of the day, and coming on again towards the evening; the reaſon of which ſeems to be, that the air being warmed by the approach of the ſun to the meridian, is able to diſſolve the morning miſt, but as the air grows colder again towards the evening, the water which had been perfectly diſſolved by the midday heat begins to be precipitated, the tranſparency of the air is deſtroyed, and an evening miſt is formed.

This phenomenon has been obſerved

ferved to prevail, in the coldeft atmofphere that has ever yet been taken notice of, on the furface of the globe; for in January 1735, when the cold in *Siberia* was equal to 157 degrees below the freezing point in Fahrenheit's thermometer, the lower region of the air was obfcured by a perpetual cloud, which was very thick in the morning, thinner towards noon, and thicker again at night*.

Mifts and dew will, generally fpeaking, be the greateft when the difference between the heat of the air in the day time, and at night, is the greateft, becaufe the hotter the day, the greater is the quantity of water which is diffolved; and the colder the night, the greater will be the

* Novi Commen. Petrop. Tom. VI. p. 429.

the quantity which is precipitated. It often happens that there is no miſt obſervable towards the cloſe of the day; this may be occaſioned, either by there being little difference in the heat of the air at noon, and at night; or, though that difference be conſiderable, yet the air may chance not to be ſaturated with water, and in that caſe it may, even in the night, be warm enough to retain all the water it had diſſolved in the day time. In cold weather the breath of animals becomes viſible, becauſe the air is not warm enough to diſ-ſolve the moiſture which is exhaled from the lungs *.

* The breath is viſible if the temperature of the air be colder than 61 degrees. Caval. on Air, p. 400. The degree of cold in which it is viſible, depends partly on the humid or dryneſs of the air.

It is not unusual for a river in winter time, to be much warmer than the air, hence the vapour which rises from the river is condensed, the air not being able to dissolve it, and a cloud or mist of small elevation, is seen to accompany the river in its course; this appearance ceases, as soon as the river is frozen, because the ice, though it be subject to evaporation, yet it does not yield so much vapour as water does *.

A cubic inch of rock salt, nitre, or any other kind of salt, is much longer in being dissolved, when it is in a compact state, than when it is reduced into a fine powder, because the salt, when in the form of a powder,

* Angara fluvius nocte glacie consistit, quo facto *nebula* illa perpetua, huc usque ex fluvio hoc evecta, cessavit. Novi Comm. Petrop. Vol. VI. p. 436.

der, has a much larger ſurface expoſed to the action of the water, than if it was in one ſolid lump. In like manner, the air will diſſolve any definite quantity of water ſooner, when the ſurface of the water is increaſed by its being in the form of a vapour, than it would do if the water was either in the form of ice, or in its ordinary fluid ſtate. The ſmoke of a chimney conſiſts principally of water, in the ſtate of vapour, and it is really aſtoniſhing, to ſee how quickly, in particular ſtates of the atmoſphere, it is diſſolved in the air.

It has been remarked, that the ſmoke of mount *Veſuvius* is much more ſtrong and viſible in rainy, than in fair weather *; if this phe-

 nomenon

* Lett. ſur la Mineral. par M. Ferber, p. 188.

nomenon does not proceed from the greater quantity of water, which is raiſed from the mountain in wet, than in dry weather; it may be accounted for, from the greater facility with which aqueous vapours are diſſolved in a dry ſerene air, than in one which is ſo ſaturated with water that it can diſſolve no more; which is the caſe, in general, of air, which parts with its water, in the form of rain or miſt.

In riding upon wet ſand in a hot day, a kind of tremulous motion in the air, to the height of a foot or more above the ſand, may be obſerved; this appearance may proceed from hence, that the water in riſing from the ſand, is not immediately diſſolved in the air. A ſimilar appearance may often be obſerved on land,

especially in corn fields towards autumn; the water which is exhaled from the ſtanding corn, not mixing itſelf at once, ſo effectually with the air, as to conſtitute with it an apparently homogeneous fluid. Something of the ſame kind happens when either ſaline ſolutions, wines, or vinous ſpirits of any kind, are poured into a glaſs of water, the compound fluid muſt be agitated, or the mixture will not at firſt be uniform.

The quantity of water contained in the air, even in the drieſt weather, is very conſiderable. We may be ſaid to walk in an ocean; the water indeed of this ocean does not, ordinarily, become the object of our ſenſes; we cannot ſee it, nor, whilſt it continues diſſolved in the air, do

we feel that it wets us; but it is ftill water, though it be neither tangible nor vifible; juft as fugar, when diffolved in water, is ftill fugar, though we can neither fee it nor feel it.*

Some philofophers have doubted, whether the weight of the air may not chiefly be attributed to the water which is conftantly fufpended in it*. But whether this conjecture be admitted or not, the power which the air has of keeping a great quantity of water diffolved in it, may very properly be applied to the illuftration of that text, in which it is faid, *God divided the waters which were under the firmament, from the waters which were above the firmament* †, without having recourfe, with *Epif-copius*,

* Boerh. Chem. Vol. I. p. 461.

† Gen. i. 7.

copius, to the very unphilofophical fuppofition of the blue fky being a folid fubftance compofed of congealed water *. Some are puzzled to find water enough to form an univerfal deluge; to affift their endeavours it may be remarked, that was it all precipitated which is diffolved in the air, it might probably be fufficient to cover the furface of the whole earth, to the depth of above thirty feet.

The air not only diffolves water, but various other vapours, which con-

 fift

* Extima five fuprema hujus aëris regio attingit fornicem illum cæruleum, in quo poftea die quarta ftellæ fixæ collocatæ fuerunt; qui fornix cæruleus mihi effe videtur aquarum in altum elevatarum, et cryftalli in morem feu condenfatarum, feu conglaciatarum, cæruleoque colore radiantium, compages. Epif. Inf. Theol. Lib. iv. c. 3.

ſiſt partly of water, and partly of volatile ſalts and oils. All vegetables, whether aromatic or not, are found to perſpire very greatly, and the matter which they perſpire, could it be condenſed, would, probably, be ſo far different from pure water, as to have both a taſte and ſmell. The matter perſpired by animals, without ſweating, conſiſts principally of water, but the water is ſtrongly impregnated with odorous particles. It has been ſaid of *Baron Haller*, that he could ſmell the perſpiration of old people, at the diſtance of ten yards; this is by no means incredible, for the human body is conſtantly enveloped in an inviſible cloud, ariſing from the great quantity of matter which is inſenſibly perſpired. *Sanctorius* eſtimates the *ſenſible* excretions of a

perſon who eats and drinks 8 lbs of food in 24 hours, at 3 lbs, and the *inſenſible* perſpiration at 5 lbs; but if we ſuppoſe the inſenſible perſpiration in this climate (which is colder than that of *Venice*, where he made his experiments) to amount only to one half of our food, we cannot but conclude, that it muſt form a great cloud around us; for 4 lbs of matter converted into a vapour as heavy as air, would occupy a great ſpace, amounting to above 50 cubic feet. The heat of the human body is generally between 90 and 100 degrees; this degree of heat is ſufficient to raiſe from it, by a kind of diſtillation, a copious vapour, which would become viſible, if the heat was increaſed; I remember having been greatly heated and fatigued in aſ-

cending the ladders from the bottom of the copper mine at *Ecton*; when I got to the top I obferved, by the light of a candle, a thick vapour reeking from the body, and vifible around it, to the diftance of a foot or more.

The difpofition of the air for diffolving either pure water, or the matter perfpired by vegetables, or animals, is very various, depending chiefly on its *denfity*, *heat*, and *dry-nefs*. The power which dogs have of fcenting the animal they are in purfuit of, muft be much affected by this difpofition of the air; for the air through which the animal has paffed, is impregnated with the matter perfpired from its body; and this matter may in one ftate of the air be fo fpeedily diffolved, and fo

much as it were diluted with air, as to make either no impreſſion, or a very ſlight one, on the olfactory nerves of the dog; whilſt in another, it may make a very ſenſible one. And if we ſuppoſe the perſpirable matter not to conſiſt chiefly of water *, but of ſuch particles as are thrown off by perfumes, without their loſing ſenſibly of their weight, ſtill it will be true, that the ſtate of the air muſt have a great influence in

* If the whole body of a naked man, except his mouth and noſtrils, was ſhut up in a glaſs caſe, ſo that no air could enter, the matter of the *inſenſible* perſpiration would, probably, be condenſed, and ſtand as dew on the inſide of the glaſs; and I apprehend it would not differ much from the matter of the *ſenſible* perſpiration, or ſweat. But if any one be diſpoſed to conſider the inſenſible perſpiration as an uncondenſable fluid, or a kind of air ſimilar

in rendering them ſenſible; ſince it has been found, that on the tops of very high mountains, where the ſtate of the air is very different from what it is in the valleys below, the moſt odorous bodies loſe either intirely, or in a great degree, their powers of exciting a ſmell.—The exiſtence of water in air is made apparent various ways.

If a bottle of wine be fetched out of a cool cellar, in the hotteſt and drieſt day in ſummer, its ſurface will preſently be covered with a thick vapour, which, when taſted, appears to

ſimilar to that which ariſes from vegetable fluids, in a ſtate of fermentation (the heat of fermenting wort being much the ſame as that of an animal body), ſtill its mixture with the atmoſpherical air muſt depend very much on the weight, humidity, and other properties of that air.

to be pure water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for glaſs is impervious to water, and the bottle remains full, and when wiped dry, it is found to weigh as much as when taken out of the cellar. The ſame appearance is obſervable on the outſide of a ſilver, or other veſſel in which iced water is put in ſummer time; and it is certain, that the water which is condenſed on the ſurface of the veſſel, does not proceed merely from the moiſture exhaled by the breathing of the people in the room where this appearance is moſt generally noticed, becauſe the ſame effect will take place, if the veſſel be put in the open air. Water which is cooled by the ſolution

tion of any ſalt, or even ſpring water, which happens to be a few degrees colder than the air, produces a ſimilar condenſation of vapour on the outſide of the veſſel in which it is contained. Theſe and other appearances of the ſame kind, are to be explained on the ſame principle. Warm air is able to retain more water in ſolution than cold air can; when therefore warm air becomes contiguous to the outward ſurface of a veſſel containing cold liquor, it is preſently cooled to a certain degree, and in being cooled, it is forced to part with ſome of the water which it had diſſolved, and this water, ceaſing to be ſuſpended by the air, attaches itſelf to the ſurface of the cold veſſel.

The more ancient philoſophers,

not ſuſpecting that water might be diſſolved in air, were of opinion that the moiſture which they obſerved adhering to the outſides of veſſels, which had been cooled by having ſnow put into them, proceeded from a tranſmutation of air into water *. But there ſeems to be no more reaſon for this ſuppoſition, than there would be for ſaying, that water was changed into ſaltpetre, from obſerving that water which had diſſolved as much ſaltpetre as it could, in a certain

* Naturæ myſtas arcano modo, ſed facili, *äerem in aquam* mediis caloribus cogere docebit abjecta hæc nix, ſi vitro conicæ figuræ, intra tripodem, apice deorſum vergente ſuſpenſo, indatur nivis vel glaciei fruſtum. Quippe ſubjecto vaſculo excipiuntur, exteriore vitri frigiditate collectæ, et laterum declivitate manantes aquæ guttæ. Bartholinus de Figura Nivis, p. 3. See alſo Boyle's Works, Vol. II. p. 297.

certain degree of heat, deposited a part of it, when that degree of heat was lessened.

Another method of proving the existence of water in the clearest air, is, to observe the increase of weight, which certain bodies acquire by exposure to the *open* air. I put upon a plate 8 ounces of salt of tartar, which had been well dried on a hot iron; the day was without a cloud, and the barometer stood at 30 inches; in the space of three hours, from 11 to 2 o'clock in the afternoon, the salt had increased in weight two ounces; in the course of a few days its weight was increased to twenty ounces, it was then quite fluid, and being distilled it yielded a pure water equal in weight nearly to the increase it had acquired from the air,

and therefore it is rightly inferred, that water was the ſubſtance which it had attracted from the air.

Strong acid of vitriol is another body which very powerfully attracts humidity from the air. An ounce of this acid has been obſerved to gain, in 12 months, above ſix times its own weight *. The power of the acid to attract water from the air, depends upon its ſtrength, for it may be ſo far diluted, that inſtead of attracting any more water from the air, it will, by evaporation, loſe a part of that which it had acquired; when it is in this ſtate, its weight varies with the dryneſs or moiſtneſs of the atmoſphere, and it becomes, when accurately balanced in a good pair of ſcales, no bad kind of an hy-

 grometer.

* Newm. Chem. by Lewis, p. 161.

grometer. The time in which any definite quantity of acid acquires its greateſt weight from the air, depends partly upon the quantity of water which is diſſolved in the air, and partly upon the ſurface of the acid which is expoſed to the air, it having been aſcertained by experiment, that the quantity attracted from the air, in a definite portion of time, is greater as the ſurface is greater. Hence, inſtead of a twelve months expoſure to the air being requiſite to make one ounce of acid of vitriol acquire ſix ounces of water, it might poſſibly acquire that weight in a few minutes, if its ſurface was enlarged in a due proportion.

Onions and other bulbous roots, when hung up in a room ſheltered om rain and dew, are obſerved to germi-

germinate, and to acquire a great increaſe of bulk, and it might thence have been ſuſpected, that they attracted much water from the air, and were increaſed in weight. But though they may increaſe in bulk, they are found to decreaſe in weight; the root itſelf, in becoming rotten, ſupplies nutriment to the germinating plant; and if it imbibes any thing from the air, it loſes that and more by perſpiration. An onion on the 26th of January, when it had ſcarce begun to ſhew any ſigns of vegetation, weighed 296 grains; on the 16th of the following May, after having put forth ſeveral ſtems in the open air, it weighed only 145 grains*.

The increaſe of weight which the human

* Novi Com. Petrop. Tom. II. p. 225.

human body, in many cases, experiences from the water which the pores of the body suck in from the air, is another very sensible proof of the great quantity of water which is constantly dissolved in the air. "Keil has proved, that a young man weakened from want of nourishment, but in other respects healthy, added eighteen ounces to his weight, in the space of one night, and this by the absorption through his pores. Another person has been seen to gain 40lbs. weight, in the same manner, in the space of a day. M. de Haen is of opinion; that dropsical patients absorb more than 100lbs. weight every day. It is supposed, that, in general, the body absorbs more than 1lb. every day by

by the pores *." The ſkin of a middle-ſized man is equal to about 15 ſquare feet; and if we ſuppoſe the ſkin of a dropſical perſon to be 20 ſquare feet, then will each ſquare foot imbibe 5lbs. or pints of water in one day.

In addition to theſe inſtances I will ſubjoin the following account, which was given me by a perſon of credit and judgment. A lad at New-market, a few years ago, having been almoſt ſtarved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 o'clock in the morning, and again at 10, and he was found to have gained near 30 ounces in weight in the courſe of an hour, though he

 had

* Treatiſe of Phyſic by Zimmerman. Vol. II p. 128.

had only drank half a glaſs of wine in the interval. The wine probably ſtimulated the action of the nervous ſyſtem, and incited nature, exhauſted by abſtinence, to open the abſorbent pores of the whole body, in order to ſuck in ſome nouriſhment from the air. Something ſimilar to this was the caſe of the negro, who, being gibbetted alive, regularly voided every morning a large quantity of urine, but diſcharged no more till about the ſame hour the next day*; the dews of the evening at Charles Town in South Carolina, imbibed by his body, ſupplying a ſuperabundance of fluids in the night, and a ſufficient quantity to ſupport perſpiration in the day. It has been obſerved, that "neither hogs

nor

* Medical Tranſ. Vol. II. p. 103.

nor beasts of burden ever drink in Jamaica, and yet they are continually sweating. The air is so moist, that the absorbing pores of these animals imbibe a sufficiency of water *." The imbibition of water through the pores of the skin is an acknowledged fact—" it is well known, that persons who go into a warm bath, come out several ounces heavier than they went in; their bodies having imbibed a correspondent quantity of water †. Part of the utility of medicated and vapour baths, depends upon this principle of imbibition by the pores: and it is said that thirst may be allayed by bathing in warm sea water, the pores im-

* Treatise of Phys. Vol. II. p. 101.

† Goldsmith's Hist. of the Earth, Vol. I. p. 238—398.

imbibing the water, and carrying it to the inteftines, but not fuffering the diffolved falt to accompany the water.

With refpect to the quantity of water fufpended in the whole atmofphere, or even in a column of the atmofphere, of a definite bafis, incumbent on any particular fpot, it cannot be afcertained with precifion, unlefs we knew fome method of depriving the air of all the water it contains, and could at the fame time make the experiment at different diftances from the furface of the earth. For it is not only probable, that a cubic yard of air, contiguous to the furface of the earth, contains at different times very different quantities of water, even at the fame place, according as the ground is moift

moiſt or dry, or the temperature of the weather warm or cold; but we have great reaſon to believe, that at the ſame inſtant of time, a cubic yard of air, which touches the ſurface of the earth, contains as much water as three or four cubic yards, which are ſituated at the diſtance of thirty or forty yards above it. For the water which riſes from the ſurface of the ocean, from the perſpiration of organized bodies, whether vegetable or animal, or from the mere action of the ſun on a moiſt earth, in being diſſolved in the air as ſoon as it riſes, makes the air near the ſurface heavier than that which is at a diſtance from it, and on that account the motion of the air, unleſs it be violent, will not readily mix the lower and heavier air with the higher

higher and lighter, and the lower air will consequently contain more water in a definite bulk, than the higher. To what has in a former Essay been observed on this subject, the following illustration may be added. If into a deep drinking glass half full of water, you gently pour a glass of port or claret, you will see the wine mixing indeed itself slowly with the water, but that part of it which is near the water, will be much more impregnated, in any definite portion of time, with water, than the more remote parts, it will be a considerable time before the water will be uniformly diffused through the wine, if they are left undisturbed; nor does a gentle undulating motion soon mix them, and this difficulty of mixing them would be still much

greater,

greater, if there was a greater difference in their respective weights, or if the upper parts of the wine were less dense than the lower. Now this is the case in the air, which is not only above 800 times lighter than water, but its parts, which are far removed from the surface, are much less dense than those which are contiguous to it. That dense air holds more water in solution than rarefied air, is proved from hence; that when common air is rarefied under the receiver of an air-pump, a part of the water which is contained is precipitated, in the form of dew; this answers to the precipitation of salt from a saline solution, when part of the water is taken away, which held the salt in solution. Hence, as cold tends to render the air more dense,

it certainly contributes to its holding more water in ſolution than it would do, if it was more rarefied under the ſame degree of heat: but as hot air diſſolves more water than cold air, and as air is rarefied by heat, it is evident, that the denſity and heat of the atmoſphere in ſome meaſure counteract each other, with reſpect to the power the air has in diſſolving water: the law according to which this power varies, in different degrees of heat and condenſation, is not determinable from any experiments which have yet been made.

It may not be improper to take notice, in this place, of an objection which is uſually made to the doctrine here advanced,——of water being ſuſpended in the air by ſolution—It is aſſerted, that water is as evapor-

able

able in an exhausted receiver, where there is no air, as in the open air*. It is certain, that heat will evaporate water, and great degrees of it may probably evaporate it faster *in vacuo* than in the open air, inasmuch as the pressure of the air may tend to obstruct the action of the heat, in converting the water into vapour. Thus, quicksilver is not, I apprehend, evaporable in the open air, yet it has long been remarked to be evaporable *in vacuo*, as may be collected from the little globules of quicksilver, generally found adhering to the upper part of a barometer, and which arise from the vapour which insensibly escapes from the surface of the quicksilver in the tube.

* Berlin Mem. 1746. Waller de Aiten. Vapo. in vacuo.

tube. But though heat may be one caufe of the evaporation of water, the attraction between air and water, upon whatever principle it depends, may be another. The fact moreover, upon which the objection is founded, is very queftionable, and not generally to be admitted. A china faucer, which contained 3 ounces of water, loft nothing of its weight under an exhaufted receiver in the fpace of 4 hours; whilft a fimilar faucer, containing an equal quantity of water, loft, in the fame time, in the open air, one drachm and eight grains; the heat of the atmofphere being between 48 and 50 degrees *.

Many readers are gratified with feeing the general progrefs of any philo-

* See Dr. Dobfon's ingenious Obfervations in Philof. Tranf. 1777, p. 256.

philoſophical opinion, from its being firſt ſuggeſted, till its being generally admitted. The hiſtory, indeed, of philoſophy, is one of the moſt pleaſing purſuits which a ſpeculative mind can be engaged in, but it requires great leiſure and ability to cultivate it with ſucceſs. It is not every diſtant hint which he throws out, that can intitle a philoſopher to the credit of being the firſt framer of an hypotheſis; nor on the other hand are we haſtily to reject the maxim, that "all novelty is but oblivion," inaſmuch as we frequently ſee old opinions putting on the appearance of new diſcoveries, from their being dreſſed out in a new form.

Natural philoſophy principally conſiſts in exploring, by experiment,

the phenomena resulting from the mutual action of different bodies upon each other. These phenomena are innumerable, no arithmetic can reckon up the various ways in which terrestrial bodies may, by natural or artificial means, be brought to operate on one another. To this cause may we attribute the immense number of volumes on experimental philosophy, which have been published in Europe since *Bacon* pointed out the proper method of studying nature. This circumstance, joined to the uniformity which must ever attend the operations of nature in similar circumstances, may justly intitle different men to the honour of having made the same discoveries, it being much easier to make an experiment, which may have been

made before, than to read all that has been written in different ages and countries on natural appearances.

Doctor Halley, in the year 1691, propofed to the Royal Society, his opinion concerning the origin of fprings: in this tract he expreffes himfelf in the following manner: "The air of itfelf would imbibe a certain quantity of aqueous vapours, and retain them *like falts diffolved in water*, the fun warming the air, and raifing a more plentiful vapour from the water in the day time, the air would fuftain a greater portion of vapour, as warm water would hold more diffolved falts, which upon the abfence of the fun, in the nights, would be all again difcharged in dews,

dews, analogous to the precipitation of ſalts on the cooling of liquors."*

M. Le Roy publiſhed an ingenious diſſertation on the ſolubility of water in air, in the year 1751; among other experiments, by which he illuſtrated his hypotheſis, he obſerves, that if a large, new, hollow, globular glaſs veſſel, with a narrow neck, be cloſely corked up in a clear hot day, the water contained, in the apparently dry air, will be precipitated, and form a dew in the inſide of the veſſel, whenever the veſſel is cooled, and that this dew will vaniſh, being re-diſſolved by the air included in the veſſel, as ſoon as the air regains its heat.

Doctor Franklin further illuſtrated this principle, of water being ſoluble in

* Philoſ. Tranſ. No. 192.

in air, in a paper which was read before the Royal Society in 1756, and afterwards printed in his works*.

In the French *Encyclopedie*, published in 1756, we meet with the following passage—On voit par la combien se trompent ceux qui s' imaginent que l'humidite qu'on voit s' attacher autour d'un verre plein d'une liqueur glacee est une vapeur condensee par le froid: cet effet, de meme que celui de la formation des nuages de la pluie, et de tous les meteors aqueux, est une vraie precipitation chimique, par un degre de froid qui rend l' air incapable de tenir en dissolution toute l' eau dont il s' etoit charge par l' evaporation dans un tems plus chaud; et cette precipitation est precisement du

 meme

* Franklin on Elec. p. 182.

meme genre que celle de la creme de tartre, lorſque l' eau qui la tenoit en diſſolution s' eſt refroidie*.

Muſchenbroek, amongſt other cauſes which he aſſigns for the ſuſpenſion of vapour, evidently alludes to the ſolution of water in air, and compares it to the ſolution of ſalts in water.†

But though a great many philoſophers had ſpoken of the ſolubility of water in air, before *Doctor Hamilton*, yet in juſtice to him it muſt be owned, that no one has treated the ſubject more diſtinctly, or applied it more ſucceſsfully to the explanation of various phenomena than he has done, in an eſſay which was read to the

† Ency. Fran. T. VI. p. 283. Fol. Ed.

† Introd. ad Phil. Nat. Vol. II. p. 965; pub. 1769.

the Royal Society in 1765, and afterwards publiſhed with other eſſays, by the ſame author.* The reader will be very well pleaſed with ſeeing this principle illuſtrated in an eſſay by Mr. White, publiſhed in 1771, in the elegant collection of Georgical Eſſays by *Doctor Hunter* †.

* Philoſ. Eſſays by Hugh Hamilton, D. D. F. R. S.

† Georgical Eſſays by Doctor Hunter, Vol. II. p. 15.

ESSAY IV.

OF COLD PRODUCED DURING THE EVAPORATION OF WATER, AND THE SOLUTION OF SALTS.

ON the 27th of March 1779, when the weather had been for ſome time very dry, I put a thermometer into a glaſs of water, which had been heated to 87 degrees, by ſtanding expoſed to the direct rays of the ſun. The thermometer was then taken out, and its bulb was held oppoſite to the ſun, which ſhone very

 bright;

bright; as the bulb grew dry by the evaporation of the water, the mercury in the thermometer ſunk very faſt; it continued for a moment ſtationary at 76 degrees, and then it roſe rapidly to 90; ſo that 11 degrees of cold had been produced during the evaporation of the water.

On another day in the ſame month, when the heat in the ſhade was 68 degrees, I put a thermometer into a glaſs of water, it ſtood at 50 degrees; upon taking it out, the mercury, inſtead of ſinking from the effect of evaporation, began *immediately* to riſe from the effect of the heat of the atmoſphere upon it. I put the thermometer into the ſame water, heated to 55 degrees, and taking it out, the mercury continued *ſtationary* for ſome time, and afterwards it began

to

to riſe. It was put into the ſame water heated to 58 degrees, and upon being taken out, the mercury did not either riſe or continue ſtationary, but it ſunk one degree; when the water was heated to 60 degrees, the thermometer, upon being taken out, ſunk 3 degrees before it began to riſe. Theſe experiments were all made in the ſhade, and it ſeems as if we might conclude from them, that 57 was the degree of heat in the water, in which the cold produced by evaporation, was juſt equal to the heat produced by the atmoſphere which then ſurrounded the ball of the thermometer.

The degree of cold produced by evaporation, depends, probably, upon the quickneſs with which that is accompliſhed: now the quickneſs

with which water, of a definite temperature, is evaporated, is influenced, partly by the degree of heat prevailing in the atmofphere; partly by the wind blowing upon the thermometer; partly by the drynefs or moiftnefs of the air; and by other caufes.

September 30th of the fame year, when the heat in the fhade was 64 degrees, and the heat of the water 60, the thermometer, upon being taken out, ftood ftationary for three minutes, and then it rofe; there was a gentle fouth wind. On the next day there was a cold dry wind from the north, the water and air were both at 56 degrees, and the thermometer on being taken out funk to 52.

Spirits of wine, ether, and many other fluids, produce cold by being eva-

evaporated, and they produce a much greater degree of cold than water, in consequence, probably, of their being more evaporable. Thus, vitriolic ether*, which is one of the most volatile fluids in nature, has been observed to lower *Reaumur's* thermometer 40 degrees below the freezing point (which answers to 90 degrees of Fahrenheit's scale)†. The experiment is most commodiously made, by applying a piece of fine linen wetted with ether upon the bulb of the thermometer, accelerating

* Ether is made by distilling a mixture of spirits of wine and oil of vitriol.—Ether may be made also by distilling spirits of wine with the several acids of nitre, sea salt, and vinegar, and it is then called the nitrous, marine, acetous ether.

† Chem. Dict. art. Ether. Or Manuel de Chymie, par. M. Baumé, p. 375.

ing the evaporation by blowing on the linen with a bellows, and moiſtening the linen as it becomes dry, or exchanging it for a freſh piece which is wetted with ether. Whoever attempts to aſcertain the degrees of cold reſpectively produced by different fluids, would do well to remark particularly the ſtate of the atmoſphere with reſpect to other circumſtances, as well as to its heat.

Sailors have a cuſtom, in a calm, to hold a wet finger up into the air, and if one ſide of it, in drying, becomes colder than another, they expect wind from that quarter. This cuſtom is not without its foundation; for an almoſt inſenſible motion of the air will evaporate the water from one ſide of the finger ſooner

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than from another, and thus produce a degree of cold.

There is a ſimilar experiment, by which any one may convince himſelf that cold is produced by evaporation; let him wet a finger by putting it in his mouth, and then hold it up in the air, even in a warm room where there is no current of air, he will find that it grows cold as it becomes dry by the evaporation of the humidity.

"The method our gentlemen make uſe of to cool their liquors, is to wrap a wet cloth round the bottle and ſet it in the land wind: and, what is very remarkable, it will cool much ſooner by being expoſed thus to this burning wind, than if you take the ſame method, and ſet it in the

the cold ſea-breeze."*—The cold is produced by the evaporation of the water from the wet cloth, and as the *hot* land-wind will evaporate the water ſooner than the *cold* ſea-breeze, it is not to be wondered at, that the liquor is ſooner cooled when placed in the former wind than in the latter.

" *Kempfer* relates, that the winds are ſo ſcorching on the borders of the Perſian gulph, that travellers are ſuddenly ſuffocated, unleſs they cover their heads with a wet cloth; but if this be too wet, they immediately feel an intolerable cold, which would become fatal to them if the moiſture were not ſpeedily diſſipated by the heat."† The cold, which is

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* Ives's Voy. p, 77.

† Treatiſe of Phyſic by Zimmerman, Vol. II. p. 151.

produced by the act of evaporation, ceases as soon as that is finished, by the cloth becoming dry.

The manner of making ice in the East Indies, has an evident dependence on the principle of producing cold by evaporation here mentioned. On large open plains the ice makers dig pits about 30 feet square and 2 deep; they strew the bottoms of these pits, about eight inches or a foot thick, with sugar canes, or with the dried stems of Indian corn. Upon this bed they place a number of unglazed pans, which are made of so porous an earth, that the water penetrates through their whole substance. These pans, which are about a quarter of an inch thick, and an inch and a quarter deep, are filled, towards the dusk of the even-

ing in the winter ſeaſon, with water which has been boiled, and then left in that ſituation till the morning, when more or leſs ice is found in them, according to the temperature of the weather; there being more formed in *dry* and *warm* weather, than in that which is cloudy, though it may chance to be colder to the feel of the human body.* Every thing in this proceſs is calculated to produce cold by evaporation; the bed on which the pans are placed, ſuffers the air to have a free paſſage to their bottoms, and the pans, in conſtantly oozing out water to their external ſurface, will be cooled in conſequence of that water being evaporated by a gentle ſtream of *warm dry* air, the power of the

* Philoſ. Tranſ. for 1775, p. 252.

the air to evaporate water depending much upon its warmth and dryneſs.

They have a kind of earthen jar in ſome parts of Spain, called *Buxaros* which are only half baked, and the earth of which is ſo porous, that the outſide is kept moiſt by the water filtering through; though placed in the ſun, the water in the pots remains as *cold as ice*:* and it probably is colder from the jar being placed in the ſun, becauſe the evaporation is thereby increaſed.

The *Blacks* at *Senegambia* have a ſimilar method of cooling water. "They fill tanned leather bags with it, and hang them up in the ſun; the water oozes more or leſs through the leather, ſo as to keep the outward ſurface of it wet, which, by its quick

* Swinburne's Trav. p. 305.

quick and continued evaporation, occaſions the water within the bag to grow conſiderably cool."†

It is common enough for labouring people, in the height of ſummer, to drink ſeveral quarts of beer or other beverage in a day; this quantity is principally diſcharged from the body by perſpiration; and the cold which is generated during the evaporation of the ſweat, greatly contributes to keep the body cool. Thus has Providence contrived to render the heat of the torrid zone leſs inſupportable to the inhabitants; an intenſe heat bathes the body in ſweat, but the ſweat being evaporated by the ſame heat which occaſioned it, a degree of cold is generated on the

† Philoſ. Tranſ. 1780. p. 486.

the surface of the body, which would not otherwise have been produced.

It seems reasonable to attribute the cold, which is produced in these and other similar circumstances, to the evaporation of the water, rather than to any other cause; because when the bulb of a thermometer is wetted with different fluids, the cold produced has a manifest dependance on the evaporability of the fluid with which it is wetted. Thus, more cold is produced when the thermometer is wetted with spirits of wine, than when it is wetted with water, because spirits of wine are more evaporable than water; and more is produced when it is wetted with ether, than with spirits of wine, because ether is more evaporable than spirits of wine. No cold is pro-

 duced

duced when the thermometer is ſmeared with linſeed oil, or other oils of a ſimilar nature, becauſe theſe oils are not ſenſibly evaporable in the ordinary heat of the atmoſphere. Strong acid of vitriol when expoſed to the air, inſtead of loſing any thing of its weight, acquires an increaſe, by attracting the humidity of the atmoſphere; and as ſtrong acid of vitriol when mixed with water, generates a degree of heat, ſo the bulb of the thermometer, when wetted with ſtrong acid of vitriol, inſtead of being cooled, is warmed, and the mercury aſcends, in conſequence of the heat produced from the union of the acid of vitriol with the water contained in the air.

When water is reſolved into vapour, by the violence of a fall from a con-

a confiderable height, the air will diffolve it fooner; and in diffolving it fooner, it will, probably, produce more cold than it would have done, if the furface of the water had not been broken: hence natural and artificial cafcades, may, probably, be ferviceable in cooling the air furrounding them. This obfervation is purpofely expreffed in different terms, becaufe, having more than once fprinkled the floor and fides of a room with water in the fummer time, when the heat of the air in the room and of the water was 68 degrees, I could not obferve that a thermometer, hung in the middle of the room, changed its degree of heat whilft the room grew dry. In very hot climates the effect may, probably, be different; thus we are told, that in

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the iſland of *St. Lewis*, in the river *Senegal*, " water poured on the floor of a room for the purpoſe of cooling the air, is dried up in an inſtant, and there is *some effect on the thermometer* placed in ſuch a room,"*

This phenomenon of producing cold by evaporation, had been mentioned by M. *Amontons* in the year 1699.† It had been noticed alſo by M. *Mairan* in 1749,‡ and by *Muſſchenbroek*, in his Eſſai de Phyſique. Profeſſor *Richman*, at Peterſburgh, gave an account of ſeveral experiments, which he had made on this ſubject in 1747 and 1748,|| but he did

* Philoſ. Tranſ. 1780. p. 485.

† Mem. de l' Acad. des Scien. a Paris, 1699.

‡ Diſſertation ſur le Glace.

|| Novi Comment. Petrop. Tom. I. for 1747 and 1748.

did not explain the ſinking of the mercury in the thermometer, whilſt its bulb grew dry, on the principle of evaporation. Dr. *Cullen* has very particularly illuſtrated this principle, in a paper publiſhed in 1756; and he has there ſhewn that the cold produced was greater, when the evaporation was made in vacuo, than in the open air.* Laſtly, Profeſſor *Braun*, to whom the world is indebted for the diſcovery of freezing quickſilver, has made a further inveſtigation of this matter, by publiſhing a table of the degrees of cold produced during the evaporation of different fluids.†

During the ſolution of ſalts in water

* Eſſays, Phyſical and Literary, Vol. II. Edinb. 1756. p. 145.

† Novi Commen. Petrop. Tom. X. 1764.

ter either cold or heat is generally produced, but more commonly cold. Fixed alkaline ſalts, Glauber's ſalt, and white vitriol, produce ſmall degrees of heat during their ſolution. Sal ammoniac produces the greateſt degree of cold, of any ſalt hitherto known.

When Fahrenheit's thermometer ſtood at 68 degrees, both in the open air, and in the water which was uſed for the experiments, I ſaturated equal portions of water with ſal ammoniac, with ſaltpetre, and with ſea ſalt. The ſal ammoniac made the mercury ſink from 68 to 42 degrees, hence, 26 degrees of cold were produced; the nitre produced 17 degrees, and the ſea ſalt produced only 2 degrees of cold. I repeated the experiment with the ſea ſalt ſeve-

ral times, and with different ſorts of it, but I could never obſerve that it produced above 2 or at moſt 2½ degrees of cold. The experiments with ſal ammoniac and ſaltpetre, agree very well with thoſe made by M. *Eller*, and mentioned in the Berlin memoires for 1750; ſince he produced almoſt 27 degrees with ſal ammoniac, and 18 with ſaltpetre. *Boerhaave*, indeed, made the thermometer deſcend through 28 degrees by diſſolving ſal ammoniac in water; but he had reduced his ſalt to a very fine powder, and dried it well before he uſed it; and a difference in the fineneſs of the powder to which the ſalts are reduced before they are diſſolved, may make a difference of a degree or two in the cold produced; for the finer the ſalt,

the

the more ſurface has the water to act upon, and the quicker will the ſolution be performed; and as the cold is produced only by the act of ſolution, the ſooner that is accompliſhed, the leſs effect will the heat of the atmoſphere have, in reſtoring to the water, during the time of the ſolution, any part of the heat it may have been deprived of, during the immediate action of the water upon the ſalt.

Does any given kind of ſalt, during its ſolution in water, produce the ſame number of degrees of cold, whatever be the temperature of the water before ſolution? I have only endeavoured to reſolve this queſtion with reſpect to ſal ammoniac, and it ſeems to me that the quantity of cold produced, is not influenced by the

tempe-

temperature of the water. In the ſummer ſeaſon when the temperature of the air, water, and ſal ammoniac were each of them 70 degrees, the water ſank during the ſolution, of as much ſal ammoniac as would ſaturate it, to 44 degrees, or through 26 degrees. I thawed ſome ſnow in winter, the thermometer ſtood in the ſnow water at the freezing point, or at 32 degrees; by putting ſal ammoniac, which was equally cold, into the water, the thermometer deſcended during ſolution to ſix degrees, or through 26 degrees.

The poſſibility of freezing water in the middle of ſummer, is rightly enough inferred from this experiment. In a tub, ſuppoſe of 3 feet in diameter, place a bucket, a little taller than the tub, of 1 foot in diameter;

meter; in the bucket hang a Florence flaſk, or a flat lavender water bottle, ſo that the mouth of the bottle may be above the rim of the bucket: fill theſe veſſels with water heated, ſuppoſe, to 70 degrees. Saturate the water in the tub with ſal ammoniac, then will the 70 degrees of heat be reduced to 44, the water loſing, during the ſolution of the ſalt, 26 degrees. The water in the bucket being ſurrounded with this cold fluid, will itſelf be cooled; ſuppoſe it to be cooled only to 50 degrees, then by ſaturating it with ſal ammoniac, it will loſe 26 degrees more of its heat, and be cooled to 24 degrees. The water in the bottle being immerſed in a fluid, heated only to 24 degrees, will ſoon be cooled below

the

the freezing point or 32 degrees, and consequently will concrete into ice.

The cold, in all these cases, is generated only during the time of the solution. The water recovers the temperature of the atmosphere sooner or later, according as its quantity is less or greater, and as the surface exposed to the air is greater or less; it is here supposed, that the heat of the atmosphere remains the same. The different degrees of cold produced by different salts, do not depend upon any general cause which has yet been discovered, nor is there any very satisfactory reason given for these, and other similar productions of cold or heat. The time may come when we shall be able to comprehend the reason why the acid of nitre has such different effects when mixed

mixed with ſnow from what it has when mixed with ſnow water; when mixed with ſnow water it excites a very great degree of heat; and when mixed with ſnow it produces the greateſt degree of cold that has ever yet been obſerved *. *Rerum natura ſacra ſua non ſimul tradit. Initiatos nos credimus, in veſtibulo ejus hæremus. Illa Arcana non promiſcuè nec omnibus patent; reducta et in inferiore ſacrario clauſa ſunt. Ex quibus aliud hæc ætas, aliud quæ poſt nos ſubibit, adſpiciet.*

* Vol. I. p. 267.

ESSAY V.

OF THE DEGREES OF HEAT IN WHICH WATER BEGINS TO PART WITH ITS AIR, AND IN WHICH IT BOILS.

THE air bubbles which, in ſummer time, adhere to the inſides of decanters, water glaſſes, and other veſſels filled with water, cannot have eſcaped the obſervation of any one; I have endeavoured to aſcertain the degree of heat in which theſe bubbles begin to be formed.

Into

Into a water glaſs filled with water I immerſed a thermometer; the heat of the water was 64 degrees; the water was ſet in a cloſet, where the ſun never ſhone, for two days; the heat remained much the ſame during that period, and there was no appearance of bubbles. The glaſs, with the immerſed thermometer, was then ſet in the ſun, and when the heat amounted to about 90 degrees, ſeveral air bubbles were found adhering to the graduated ſide of the thermometer, and ſome were beginning to be formed on the bottom and ſides of the glaſs.

Having frequently ſeen the inſides of veſſels containing water, ſtudded with bubbles, when the heat, it was apprehended, was much leſs than 90 degrees; I put a thermometer

ter into a water-glaſs at a time when it abounded with bubbles, and found that the heat of the water was not above 64 degrees.

The reſult of this experiment being very different from that of the preceding, in which the air did not begin to ſeparate itſelf from the water till the heat was about 90 degrees, I was for ſome time at a loſs how to account for the difference; recollecting, however, that the water, which required 90 degrees of heat before it parted with its air, was pumped from a well fed by a ſtream, which had run four miles in the open air; and that the other water, which let go its air at 64 degrees, was pumped from a well fed by ſubterraneous ſprings, I attributed the difference in the degree of heat

requiſite to make theſe waters part with their air, to the different quali-ties of the waters.

In order to try theſe waters under ſimilar circumſtances, two water-glaſſes were filled, one with common well water, another with that which had been ſupplied by the ſtream; on being expoſed to the air, bubbles began to be formed in the well wa-ter when the heat amounted to 60 degrees; the other did not part with any of its air in the ſame degree of heat.

I was at firſt diſpoſed to think, that theſe experiments pointed out a general difference between river water and well water, with reſpect to their diſpoſition for retaining or part-ing with their air; but the following experiment, made at a different ſea-

ſon of the year, convinced me that the conjecture was not well founded.

In November, when the heat of the air had been for ſome time about 50 degrees, I took three water-glaſſes, one was filled with rain water immediately after it had fallen, another with the common well water, the third with the water which came from the ſtream: the heat of theſe ſeveral waters was the ſame, namely 48 degrees: they were all gradually warmed, by ſetting the water-glaſſes in hot water, and they all began to exhibit bubbles when the heat was about 60 degrees: I thought the rain water ſhewed the moſt bubbles.

Hence it is plain, that the ſtream water does not differ from rain or well water, except accidentally, as to the degree of heat in which it parts

 with

with its air. The first experiment, in which the bubbles were not formed till the heat was 90 degrees, was made after there had been several days of very hot weather, and the water in being exposed, during its course, to the action of the sun, had probably lost a considerable portion of its air before it arrived at the well. All river water has a vapid taste in summer-time, which is in part, probably, occasioned by having lost some of its air, in consequence of its being exposed to the rays of the sun. Water-drinkers are desirous of having water fresh from the well, especially in summer-time; and not without reason, for the heat in that season being generally above 60 degrees at our principal meal time, the water, if it has been long exposed

to the air, muſt have ſuffered a change of quality, not only from its increaſe of heat, but from a conſequent loſs of a portion of its air. The water which ſupplies the warm bath at *Matlock*, and which is drunk by invalids, is 68 degrees warm; hence it has loſt a part of the air which it would naturally contain, and, except in very hot weather, it does not exhibit any air-bubbles in the decanters.

The air begins to be *viſibly* ſeparated when the heat is about 60 degrees; but it begins, probably, to be *inviſibly* ſeparated when the heat is much leſs: and the leaſt heat will be requiſite to ſeparate it, when the weight of the atmoſphere is the leaſt.

Philoſophers have invented various methods, equally concluſive, of

 ſhew-

ſhewing, that water, in its ordinary ſtate, contains diſſolved in it a portion of air. And they have ſhewn, that water which has loſt a portion of this air, either by being *frozen*, or *heated*, or by long continued *agitation*, or by other means, has the property of re-abſorbing as much air from the atmoſphere as it had loſt; and they have ſhewn, that this abſorption is the ſtrongeſt at firſt, and becomes leſs and leſs powerful, as the water becomes more and more impregnated with air. Theſe and ſimilar obſervations render it probable, that water is as capable of diſſolving a certain portion of air, as it is of diſſolving a certain portion of any particular kind of ſalt. The quantity of air, which water is capable of diſſolving and retaining in ſolution, depends partly upon

upon the temperature of the water, partly upon the weight of the atmoſphere, and partly, I conceive, upon the water's purity. From theſe circumſtances, as well as from ſome others which might be attended to in making the experiment, it has happened, that authors have given very different accounts of the quantity of air contained in water. *Boerhaave* has an experiment *, from which he infers, that there may be ſeparated from water a quantity of air equal in bulk to the water; the experiment is ingeniouſly contrived, but the concluſion, I think, is liable to ſome objections. The *Abbé Nollet* ſays, that water which has been previouſly purged of air, abſorbs in ſix days, one thirtieth of its bulk †.

 Doctor

* Boer. Chem. Vol. I. p. 521.

† Hiſt. de l'Acad. 1743.

Doctor Hales obtained by diſtillation one cubic inch of air from fifty-four cubic inches of water *. Mr. *Eller* is of opinion that the portion of air contained in water does not exceed the 150th part of its bulk †. Dr. *Prieſtley* found that a pint of his pump water contained about one fourth of an ounce meaſure of air, that is, the bulk of the water was to that of the air it contained, as 64 to 1 §. *M. Fontana* ſays, that the water of the *Seine* at *Paris*, after being long boiled, abſorbs in forty days one twenty-eighth of its bulk of common air ‡. Laſtly, *M. Cavallo* obſerves, that in a temperate degree of heat, and when the barometer is about

* Veg. Stat. c. 6. † Berl. Mem. 1750.
§ Philoſ. Tranſ. 1772, p. 248.
‡ Philoſ. Tranſ. 1779, p. 439.

about 29 $\frac{1}{2}$ inches, water abſorbs about one fortieth of its bulk of common air *.

It has been remarked in another place †, that the *atmoſpherical* air conſiſts, in part, of *fixed* air; and ſome of the moſt ſtriking differences between fixed and atmoſpherical air were there mentioned. If a bubble of atmoſpherical air of a definite bulk, ſuppoſe it equal to eleven pints, be expoſed to the action of a ſufficient quantity of water, which has been purged of its air by boiling, the *whole* of the bubble will, in a proper length of time, be abſorbed by the water; but when about ſeven pints, or even a leſs portion, have been abſorbed, the remaining part will

* Cavallo on Air, p. 213.

† Vol. II. p. 247.

will resemble fixed air in this—that a candle will not burn in it *. It is very probable that water which has not been boiled may have a similar effect under certain circumstances. —" The wells at *Utrecht* are from 8 to 20 feet in depth; it has been the custom to make use of pumps to raise the water, and they are then covered over with a kind of arch. When, after a certain period of time, the wells are opened, on any account, it is necessary to leave them uncovered for 12 hours, before any person descends into them; whoever should venture to go down into them sooner, would expose himself to immediate death. The air of these wells extinguishes candles like that acquired from fermentation or effer-

* Philos. Trans. 1772, p. 247.

effervefcence *." — Stagnating air, which has brooded, though but for a fhort time, even over running water, is found to be fo greatly altered in its quality, that it will extinguifh flame, though it be fufficiently pure to fupport animal life. I was informed of this fact by a miner in Derbyfhire, who had frequently verified it by his own experience. In order to free a mining diftrict from water, they frequently dig for miles together fubterraneous aqueducts; fupporting the fides and roof with timber or ftone. The mouths or outlets of thefe aqueducts or *foughs* being below the level of the diftrict to be drained, there is a conftant ftream of water flowing through them. Thefe *foughs* are many of them

* Lavoifier's Effays, p. 118.

them high enough for a man to walk upright in them, the water reaching to his middle or higher; and men with lighted candles frequently walk through them from one end to the other, in order to prevent obſtructions; it ſometimes however happens, that by the falling in of the roof, or other accidents, the ſough is in part dammed up: when this is the caſe, the water beyond the place where the obſtruction is, riſes to the roof of the ſough, and thus prevents a circulation of air, though there is ſtill a diſcharge of water through the mouth of the ſough. When an accident of this kind happens, men are ſent with candles in their hands to find out and remove the obſtruction, but before they have walked fifty yards from the mouth of the

ſough, the candles go out, though they perceive no difficulty in breathing, and this extinction of the candles will take place in 24 hours after the ſtoppage of the water has commenced.

Fahrenheit, *Boerhaave*, and other philoſophers had obſerved, that the degree of heat, requiſite to make water boil, was variable according to the purity of the water, and the weight of the atmoſphere. Within the uſual limits of 28 and 31 inches in the barometer, *Boerhaave* was of opinion *, that there would be a variation in the heat of boiling water, amounting to 8 or 9 degrees. This ſubject has of late been examined with great accuracy by Mr. *de Luc*, and Sir *George Shuckburg*; and Mr. *Cavallo*

* Chem. Vol. I. p. 171.

Cavallo has given us the reſult of their experiments in the annexed table, which is formed according to the ſcale of *Fahrenheit's* thermometer *.

TABLE.

Height of the Barometer.	Heat of boiling water according to Mr. de Luc	Heat of boiling water according to S. G. Shuckburg
	Parts of a Deg. deg.	Parts of a Deg. deg.
26	205,17	204,91
26½	206,07	205,82
27	206,96	206,73
27½	207,84	207,63
28	208,69	208,25
28½	209,55	209,41
29	210,38	210,28
29½	210,2	211,15
30	212	212
30½	212,79	212,85
31	213,57	213,69

* Cavallo on Air, p. 215.

The

The following experiment is curious in itſelf, and it illuſtrates both the nature of boiling in general, and what is here advanced relative to the heat of boiling water under different preſſures of the atmoſphere. I hit upon it many years ago, when I had another object in view. My deſign was, to exhibit a ſtriking inſtance of the increaſe of dimenſions produced in fluids by various degrees of heat: in order to this, I took a large glaſs veſſel, reſembling in ſhape ſuch mercurial thermometers as have a bulb at the bottom *; the bulb of this veſſel held above a gallon, and the ſtem had a ſmall diameter, and was above two feet in length. Into this veſſel I poured boiling

* A veſſel of this ſhape is uſually called a *Matraſs*.

boiling water, and having filled it up to the very top of the ſtem, I corked it with a common cork as cloſe as I could. The water and the cork were at firſt contiguous to each other; but in a very little time the water began to grow cold, and as it grew cold, it contracted itſelf and ſunk very viſibly in the ſtem; and thus the firſt intention of the experiment was fully anſwered. But an unexpected phenomenon preſented itſelf,—the water, though it was removed from the fire,—was growing cold,—and had for ſome time intirely ceaſed from boiling, began to boil afreſh very violently, the bubbles were large and numerous, and continued to aſcend into the ſpace between the ſurface of the water in the ſtem, and the cork, where

they

they burſt, for above two hours. When a hot iron was applied to that part of the ſtem, through which the water, in contracting itſelf, had deſcended, the ebullition preſently ceaſed; it was renewed when the iron was removed; and it became more than ordinarily violent, when, by the application of a cloth dipped in cold water, that part was cooled. There is no great difficulty in accounting for theſe ſeveral appearances: by the ſinking of the water in the ſtem a *kind of vacuum* is left between its ſurface and the cork; water and other fluids boil with leſs degree of heat, when the preſſure on their ſurface is diminiſhed; here the preſſure of the atmoſphere is wholly removed by means of the cork, and the water continues to boil, though its heat be

conſtantly decreaſing. The interval between the water and the cork is not, as will be ſhewn preſently, a *perfect vacuum*; it is occupied either by the vapour of the water, or by a ſmall portion of air, or by both; heat increaſes the elaſticity of both air and vapour, and thus augments the preſſure upon the ſurface of the water, hence, the ceaſing of the ebullition on the application of the hot iron; cold diminiſhes the elaſticity of air, and condenſes vapour, and thus, the preſſure upon the ſurface being leſſened by the application of the cold cloth, the ebullition of the water became more violent. When the water ceaſed boiling I poured it on the bulb of a thermometer, and found that its heat was only 130 degrees.

Another circumſtance deſerving of notice remains to be mentioned. When the water was become cold, it had ſunk through the whole ſtem, and through part of the bulb; I then inverted the veſſel which contained it, into a tub of water, and obſerved upon the bottom of the bulb a large circular ſpot void of water. I conſidered this ſpot as a perfect vacuum, for it anſwered to the ſpace which the water, in contracting itſelf, had deſerted; and the vapour which, whilſt the water was warm, might have been ſuppoſed to occupy that ſpace, I was perſuaded, was condenſed by the cold: in order to ſee whether it was a *vacuum* or not, I pulled out the cork, whilſt it was under the ſurface of the water into which the veſſel was inverted, being

 certain

certain that if it was a vacuum, it would be inſtantly filled with water, which the preſſure of the atmoſphere would make to aſcend through the ſtem. In fact, the circular ſpot was greatly diminiſhed by the aſcent of the water, but never (for the experiment was often repeated) taken wholly away. What remained muſt have contained either air, or ſome other fluid, whoſe elaſticity was a counterpoiſe to the preſſure of the atmoſphere, on the ſurface of the water in the tub. It would be too haſty a concluſion, from this circumſtance, to attribute the formation of the bubbles to the particles of air, from which water cannot be ſeparated by long boiling*; for it may be,

* Licet diu ebullierit aqua non erit aeris expers. Muſchen. de Aqua.

be, that this ſmall portion of air arofe from the ſubſtance of the cork, or from the air in the water of the tub, that water having not been boiled; or it may have been intangled in the parts of the boiling water, as it was poured into the veſſel, and not have had time to eſcape before the cork was inſerted; or, laſtly, which is the leaſt probable ſuppoſition, the vapour ariſing from the water may not be capable of being totally condenſed.

The phenomenon of the boiling of fluids is not very ſatisfactorily explained. It is clear, I think, from the experiment of which I have given an account, that it cannot be attributed, in all caſes, either to the eſcape of air from the interſtices of water, or to the matter of fire, as it

is called, pervading the water; for the water continued boiling for two hours after it was removed far from the fire; and the air, if it contained any, was utterly inadequate to the formation of the numerous bubbles. *Boerhaave* has remarked, that bubbles of the kind here ſpoken of contain no air, but he has not aſſigned the cauſe of their origin: Dr. *Hooke* aſcribes them to the ſubtle parts of the water, which, when the preſſure of the air is removed (probably by means of an air pump), are able to acquire the form of vapours, by that ſmall degree of heat which is left in the ambient air*: and other philoſophers † have adopted this idea, without hinting at, what Hooke ſup-poſed,

* See Birch's Hiſt. of the Royal Society.
† The Abbe Nollet and Dr. Hamilton.

posed, a different degree of volatility in the parts of the water.

From what has been advanced we may conclude, that the *Almighty*, when he separated the chaotic mass into air and water, did not render these two oceans of matter so wholly heterogeneous from each other, as that they should be incapable of contracting any union together; they have, on the contrary, such a disposition to unite, as seems to indicate their having had a common origin; and were it not for the intervention of heat, they would, probably, unite, and again compose a common mass. The water on the surface of the earth is constantly replete with air, and the atmosphere is replete with water. The numerous tribe of aquatic animals,

mals, which inhabit the ocean of water, would perifh, if it contained no air; and it is not an improbable conjecture, that the animals which exift in this ocean of air, would perifh if it contained no water. The air, moreover, by being abforbed into the water, and afterwards feparated from it by the action of the fun, to which it is daily expofed, is rendered abundantly more fit for animal refpiration than common air; and this purified air (the quantity of which, confidering the great extent of the furface of the earth which is covered with water, muft be very confiderable) cannot but be one great means of reftoring to the whole mafs of air, thofe falubrious qualities of which it is daily deprived, by the

refpi-

respiration of animals, the *putrefaction* of bodies, the *combustion* of fuel, and other causes *.

* Dr. Priestley has observed, " that the same water, which, if examined immediately, gives only a small quantity of bad air, yields *spontaneously* about ten times the quantity of pure dephlogisticated air, after standing some time exposed to the *sun*." Phil. Trans. 1779, p. 377. An animal will live five times as long in what is called here dephlogisticated air, as it will in common air of the best quality.

ESSAY VI.

OF WATER IN A SOLID STATE; OF THE HEAT OF SPRING WATER; AND OF A PROBABLE CAUSE OF THE IMPREGNATION OF SULPHUREOUS WATERS.

THE mind of man admits with great reluctance, the truth of every testimony concerning matters of fact, which happen to be repugnant to the uniform experience of his senses; hence the general back-

 wardness

wardneſs to believe the miracles recorded in the bible; and hence the *Dutchman* who informed the king of *Siam*, that water in his country would ſometimes, in cold weather, be ſo hard that men walked upon it, and that it would bear an elephant, if he were there, was eſteemed a perſon unworthy of credit, the king, as Mr. *Locke* relates the ſtory, ſaying to him, "Hitherto I have believed the ſtrange things you have told me, becauſe I look upon you as a ſober man, but now I am ſure you lie*."

Mahine, the native of *Borabora*, could ſcarcely be perſuaded, even by the information of his ſenſes, of the reality of the ſame effect. The appearance of "white ſtones," as he called

* Locke's Eſſay on the Hum. Und. B. IV. C. XV.

called hail, which melted in his hand was altogether miraculous to him; and when he had been with difficulty convinced that an extensive field of ice was not common land, he was determined at all events to call it "white land," by way of distinguishing it from all the rest *.

This determination of the savage was made in the true spirit of philosophy, for ice in small particles is a species of earth, and in solid masses it may be considered as a kind of transparent stone. *The waters*, says Job †, speaking of the effect of frost, *are hid as* with *a stone*; that is, water conceals its nature, by assuming a stone-like hardness and consistence when it becomes ice. The Russians applied

* Forster's Voy. Vol. I. p. 530.

† Chap. xxxviii. 30.

applied ice to the ſame purpoſes with ſtone, at the whimſical marriage of *Prince Gallitzen*, in 1739; an houſe, conſiſting of two apartments, was built with large blocks of ice, the furniture of the apartments, even to the nuptial bed, was made of ice; and the icy cannon and mortars, which were fired in honour of the day, performed their office more than once without burſting *.

Ice, however, differs from all other earths and ſtones, not only in its melting in a much leſs degree of heat than any of them, but in its being ſubject to a conſtant diminution of its weight when expoſed to the open air, in the greateſt degree of cold. It generally becomes fluid in the 33d degree of heat, as indicated

* Manſtein's Mem. of Ruſſia.

cated by Fahrenheit's thermometer; and Mr. Boyle, by expoſing in a good balance ſomewhat leſs than two ounces of ice to a ſharply freezing air, a little before midnight, found it in the morning diminiſhed in weight ten grains *. It is probable, that this diminution of the weight of ice, is owing to the abraſion of its parts by the action of the air. The particles of air are thought to be larger than the particles of water, and may by their motion acquire force enough to ſeparate the particles of ice; or if this ſhould not be admitted, it muſt be remembered, that the air always contains a great quantity of water, the particles of which, when converted into particles of ice, though in this country they are ſeldom

* Boyle's Works, Fol, Vol, III. p. 66.

dom large enough to be ſeen, always make themſelves felt by impinging upon our ſkin: theſe icy particles when put in motion may abrade the ſurface of a maſs of ice, and cauſe thereby a conſtant diminution of its weight. In confirmation of this explanation it may be obſerved, that ice ſuffers no loſs of its weight in a veſſel devoid of air, nor in a cloſe veſſel full of air*. That the icy particles, contained in a freezing atmoſphere, ſhould be able to act upon ice, cannot be a matter of difficult conception to thoſe who recollect, that the hardeſt bodies in nature ſuffer a diminution of their weight, by the friction of the minute parts of the ſame kind of bodies; diamond

* Hamilton on the Aſcent of Vapours, p. 71.

mond dust being essentially necessary for the cutting or polishing of diamonds.

That water was diminished in quantity by being frozen, was known to *Hippocrates*; for he expressly says, that if a given quantity of water be frozen, and afterwards thawed, it will not fill the same vessel it would have done before it was frozen *. *Pliny* was of the same opinion with Hippocrates, and they both of them attribute this diminution of weight to the separation of the more subtile parts of the water during congelation†. The principal cause of the loss of weight, sustained by water when changed into ice, seems to be the incessant

* Hippoc. de Aqua.

† Plin. Hist. Nat. Lib. II. S. 61. & Lib. XXXI. S. 3.

incessant action of air upon its surface; it is true, however, that water is, by freezing, deprived of the greatest part of the air with which, in its fluid state, it is ordinarily saturated; and this separation of its air may contribute something towards the diminution of the water's bulk; since water, when saturated with air, is somewhat greater in bulk than when deprived of it.

It is easy to apprehend, that the loss of weight which any given quantity, suppose a cubic foot, of ice will suffer by exposure to the air in a given time, will depend, partly upon the hardness or softness of the ice, partly upon the temperature of the atmosphere, with respect to the degrees of cold and humidity, partly upon the velocity of the wind which

brushes

brushes its surface, and probably enough upon the agency of other causes with which we are less acquainted. Some philosophers have estimated, in general terms, the loss of weight sustained by a certain weight of ice, without specifying the magnitude of the ice's surface; others, with more accuracy, have mentioned both the weight and surface of the ice exposed to the air, but then they have either omitted to speak of the ice's consistency, the temperature of the atmosphere, the force and direction of the wind, or they have expressed themselves in very indefinite terms concerning these points, so that we cannot be said to have hitherto gained, from their experiments, any precise information upon the subject. As to the fact itself, the most com-

mon obfervation is fufficient to af-
certain us of its truth. In long con-
tinued frofts, the ice formed in ponds,
and other fmall collections of water,
is fenfibly diminifhed every day,
and often wholly evaporated; and a
fall of fnow may be feen confider-
ably wafted in a few days, in the
fevereft feafon.

Nowithftanding this diminution
of weight, to which both ice and fnow
are fubject in the coldeft weather, and
the thaw which they experience in
the hotteft, yet fome have doubted
whether the quantity of congealed
water be not an increafing quantity
upon the furface of the earth; and
have even thought, that the globe
of the earth muft in procefs of time
refemble an egg, having its diameter
from pole to pole, longer than the
equa-

equatorial diameter, on account of the conſtant accumulation of frozen water at the two poles.—" After ſo many years lapſe, it cannot be, I think, but that the diameter of the earth from pole to pole, from the top of the ſnow at one end of the earth, to the top of it at the other end, is much longer, than in any part under the equator, though at the creation it were, (as I believe) made ſpherical *."

In ſome mountainous countries, the proportion between the ſnow which falls at one ſeaſon of the year, and that which is diſſolved in another, approaches ſo near to an equality, that upon the ſame ſpot, the ſnow may in one year be ſeen quite through the year, in another, the

* Childrey's Brit. Bacon, p. 148.

the laſt ſpeck of it will vaniſh in a few weeks or days, before a new ſupply is brought by the approach of winter. In colder climates, the utmoſt power of the ſummer ſun is not able to melt all the ſnow which falls in the winter. In aſcending mount *Etna*, the *Alps*, or the *Andes*, though the lower parts are found to be rich in vegetation, yet you ſoon come to a region covered, as it ſhould ſeem, with everlaſting ſnow: the height at which this region commences, does not admit much variation in the ſame latitude, but is very different in different latitudes. It begins at the diſtance of near three miles above the level of the ſea, under the equinoctial line; and at each pole, probably, it is not removed from that level ſo many hundred feet;

feet; it is found to be 600 yards nearer to the level of the *sea* at *Teneriffe* than under the equator; and above 1200 yards nearer in *Switzerland* than at *Teneriffe* *.

Not only the tops of high mountains in every quarter of the globe are covered at all ſeaſons of the year with ſnow, but the ocean both in the northern and ſouthern hemiſphere is, in high latitudes, replete with immenſe mountains, and extenſive plains of

* Hiſto. Nat. des Glaciers Suiſſe.—The author ſays, enfin la plupart des Montagnes voiſines des poles ſont couvertes juſqu'à leur pied de neiges perpetuelles. This obſervation muſt not be admitted without reſtriction, if it be at all true, ſince in Greenland, and in the latitude 79 degrees 44 minutes north, the feet of the mountains are in certain ſeaſons freed from ſnow. See Crantz's Hiſt. of Greenland, Vol. I. p. 30. and Phipps's Voy. p. 52 and 79.

of ice, in the greateſt heats of ſummer; and hence it has appeared probable to many, that both the ſnow upon the land, and the ice upon the ſea, receive an augmentation every year, from the continued agency of the ſame cauſe which firſt produced them.

A philoſopher, well acquainted with the nature of the Alps, expreſſes himſelf upon this ſubject in the following manner: "One cannot doubt concerning the increaſe of all the Glaciers of the Alps; for their very exiſtence is a proof, that in preceding ages the quantity of ſnow which has fallen during the winter, has exceeded the quantity melted during the ſummer. Now not only the ſame cauſe ſtill ſubſiſts, but the cold, occaſioned by the maſs of ice already formed,

formed, ought to augment it ſtill farther, and thence both more ſnow ought to fall, and a leſs quantity of it be melted *." If this be admitted, the time will undoubtedly come when the ſea will be diminiſhed in depth, if not dried up by the converſion of the water, which is daily raiſed from it, into ſnow or ice; and had the world been as old, as ſome are fond of ſuppoſing it to be, we ſhould, probably, have had no water upon its ſurface at the preſent day. However, it muſt be owned, that no argument can be drawn againſt the antiquity of the world, from this conſideration, becauſe there is reaſon to believe that the ice and ſnow upon the ſurface of the earth are not annually increaſing in quantity.

* De Luc de l'Atmoſphere, Vol. II. p. 328.

tity. For, besides the heat of the air in summer, there is another cause which tends to prevent an indefinite augmentation of congealed water— the internal heat of the earth. The general heat of the springs of water, situated deep in the bowels of the earth, is 48 degrees; in mountainous countries, I suspect it to be somewhat less, but sufficient, notwithstanding, for the purpose here mentioned. When the snow, incumbent on any spot of ground, is but thin, it may so far cool the earth, that its internal heat may not be able to dissolve it; but when the bed is thick enough to protect the earth from the influence of the atmospherical cold, that surface of the snow which is contiguous to the surface of the earth, may, even in the coldest

coldeſt winters, receive more heat from the earth than it does cold from the atmoſphere, and, on that ſuppoſition, I ſee no abſurdity in admitting, that it may be diſſolved at all ſeaſons of the year.

The fact I believe is certain, that ſtreams of water iſſue from the bottom of the *Glaciers* in the *Alps*, in the greateſt ſeverity of winter; ſo that whether the internal heat of the earth be admitted, or not, as a cauſe ſufficient to explain the phenomenon, a conſtant thaw of the ice or ſnow, which is contiguous to the ſurface of the earth in the Alps, cannot be denied; and this, added to other cauſes, may render it probable that the quantity of congealed water has its *limit*, even in the coldeſt climates.

The

The ordinary heat of ſpring water, which does not feel the viciſſitudes of the temperature of the atmoſphere, is here ſaid to be 48 degrees of Fahrenheit's thermometer; it may be worth while to add a few remarks on this ſubject.

In Auguſt 1778, when the heat of the air was 72 degrees, I tried, on the ſame day, the temperature of ſeveral ſprings, reputed cold, in the neighbourhood of *Matlock*; and I found them varying in heat from 50 to 54 degrees. This variation, probably, proceeds from their ſubterraneous paſſages being ſituated at different diſtances from the ſurface of the earth, which was then much warmed by the heat of the ſummer. Or it may proceed from the ſprings being more or leſs mixed with the

water

water which ſupplies the warm baths, the heat of that water being 68 degrees. There is a ſubterraneous paſſage upon the ſide of the hill near the *new* bath at Matlock, which terminates in a large cavern, ſituated under one of the fields in the midway between the *new* and the *old* bath; and from this cavern, which is always full, iſſues the warm water which ſupplies both the baths; and it may probably ooze out in different directions, and in different quantities, ſo as to make the neighbouring ſprings participate more or leſs of its warmth.

At *Lord Godolphin*'s houſe on *Gogmagog* hills, near *Cambridge*, there is a well, above 230 feet in depth, which is dug through a ſtratum of chalk; I have frequently examined the heat of the water of this well,

and conftantly found it to be 50 degrees. At *Cherry Hinton*, a village fituated at the bottom of thefe hills, there iffues from the chalk a very copious fpring; the heat of this water, as it bubbles out of the earth, is, at all feafons of the year, 50 degrees. I have tried the heat of fome deep wells dug in chalk at *Bury St. Edmund's*, and found it variable from 50 to 52 degrees—— "It has been long and generally obferved, that as far as the limeftone extends, that tract of ground makes the fnow that falls on it, thaw or melt fooner than it does on the neighbouring lands *." This is Mr. Boyle's obfervation concerning fome limeftone land in Ireland, and he fays its truth was confirmed to him by a Derby-

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* Boyle's Works, Vol. IV. p. 278.

ſhire miner, who aſſured him, that on contiguous diſtricts of land, ſnow was obſerved to diſſolve much ſooner on the ſoil which covered limeſtone, than on that which covered freeſtone. If theſe obſervations may be depended on, we may, perhaps, in general infer that the heat of calcareous ſtrata is greater than that of other kinds of ſtrata, and this would furniſh a reaſon for the ſprings in chalk countries being of the warmth of 50, though the ordinary heat of ſprings be not above 48 degrees.

In the middle of ſummer, when the air was 72 degrees hot, I tried the heat of ſome ſprings at *Harrowgate* in Yorkſhire. Pump-water at the *Granby* Inn 48 degrees.—Old Spaw 45 degrees.—*Pewit* or *Tewit*

 well

well 48 degrees.——Sulphur well 50 degrees. The cold well at *Buxton* examined at the ſame time of the year was 48 degrees, and the famous Spaw at *Llanrhard'r* in *Denbighſhire* was alſo 48 degrees? St. *Winifred's* well, at Holywell in Flintſhire, was conſiderably warmer, the thermometer when held in the ſpring as it roſe out of the earth, ſtanding at 54 degrees. I have tried a great many other ſprings in different parts of Great Britain, and found the heat of moſt of them to be included between the limits of 48 and 54 degrees, the mean of which is 51. Springs on the ſides of high mountains may, probably, participate of the cold which is found to be greater in elevated than in low ſituations. There is a ſpring by the ſide of the turn-

turnpike road leading over the high ground called *Otley Shevin* in Yorkshire; I observed the heat of this spring in September, when the air was warmed to 62 degrees, to be not 48, but only 45 degrees. The mean heat of springs near *Edinburgh* is said to be 47, and at *London* 51 degrees *: this diversity depends, probably, on the different elevations of London and Edinburgh above the level of the sea.

I have mentioned the *Sulphur* well at *Harrowgate*, according to its usual appellation at that place, without taking upon me to decide the long controverted question, concerning the existence of sulphur in that and other waters of the same kind. *Sulphur* has been long esteemed a

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* Philos. Trans. 1775, p. 460.

mineral body very common to be met with in waters; and all thofe waters which have a ftrong fetid fmell, refembling that of a foul gun, have been efteemed to be more or lefs impregnated with fulphur. However, Dr. *Hoffman* feems to doubt much of its exiftence in the greater number of fuch waters; and Dr. *Lucas* has affirmed, that it is not to be found in the form of fulphur in any water whatever; not even in that of *Aix-la-Chapelle*, where a true and perfect fulphur is found on the upper parts of the conduits through which the water paffes; for he fays, that, ftrictly fpeaking, thefe waters do not contain fulphur fubftantially diffolved in them, but are impregnated with a phlogifton and an acid, the principles of fulphur; which be-

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ing in a volatile ſtate, are ſublimed, meet on the ſurface of the conduits, and there unite into a true and perfect ſulphur, which did not naturally exiſt in the water *." The author, from whom I have made this extract, informs us, that Dr. *Rutty* maintains the exiſtence of ſulphur in mineral waters; and that both Dr. *Shaw* and Dr. *Short* found ſulphur in Harrowgate water. Notwithſtanding the teſtimony of ſuch eminent phyſicians, the more recent opinion of a phyſician, whom Dr. *Monro* conſulted on the ſubject in 1768, is againſt the exiſtence of ſulphur in ſuch waters. "I have taken particular notice of every appearance of the Harrowgate waters, and muſt

* Monro on Mineral Waters, Vol. I. p. 30 and 196.

own I never obſerved any appearance of ſulphur floating in them, nor any ſcum at the top of the well; neither could I meet with any perſon in that quarter, who remembered the appearance of real ſulphur ſublimed, upon taking up the ſtones at the bottom of the well, as mentioned by Dr. *Neal* *."—I beg leave to add my own obſervation on the ſubject, which I made in 1780. The water in the well riſes into a circular ſtone baſon; a whitiſh cruſt adheres to the ſtone, where it is contiguous to the ſurface of the water; I ſcraped off a portion of this cruſt, and putting it on a hot iron, I found that it burned with the *flame* and *ſmell* of *ſulphur*. I do not think that this experiment abſolutely warrants us to con-

* Monro on Mineral Waters, Vol. I. p. 196.

conclude, that *actual sulphur* is contained in this and other waters generally denominated sulphureous; we justly infer from it, that something is sublimed from the water, which either of itself is sulphur, or which in conjunction with the air, or some other principle, constitutes sulphur.

The prosecution of this subject would lead to speculations too abstruse for my design; the following experiment, however, which I have frequently made, will, I hope, throw no inconsiderable light on the cause of the impregnation of sulphureous waters in general.

The acid of vitriol does not act upon the common Derbyshire lead ore, except when it is assisted by heat, it then dissolves it, and a great

escape of air is observed: I made this air, as it was discharged from the ore, pass through a high-bended tube into a bottle full of pump water: the water, in a very little time, acquired the *fetid smell* of Harrowgate water,—its taste was the same as that of such sulphureous waters as contain no salt,—it was perfectly *transparent*, but in the course of 24 hours it became *cloudy*, and lost most of its smell,—it did not suffer any *precipitation* by the addition of the acid of vitriol,—*silver* was *blackened* both by being put into this water, and by being exposed to the vapour which arose from it; from all these circumstances, it may properly enough, I think, be called an *artificial sulphureous water*.

I have observed the same pheno-

mena

mena when, inſtead of lead ore, I uſed *black jack*; and I remember that once having placed a bottle, containing black jack and acid of vitriol, ſo that its neck leaned againſt a plaiſtered wall, I obſerved ſome days afterwards, that the wall was ſtained, to the diſtance of above a foot from the mouth of the bottle, of a purple colour, reſembling the purple ſediment often found in ſulphureous wells.

Air of the kind here ſpoken of, may be ſeparated from other ſubſtances, as well as from lead ore and black jack, and by other means, as well as by the acid of vitriol; and it ſeems very probable, that the waters uſually called ſulphureous, are impregnated with this kind of air, which has been ſeparated, in the

 bowels

bowels of the earth, from particular minerals, especially fulphureous ones. It has been remarked of Harrowgate water, that as it springs up it is clear and *fparkling*, and throws up a quantity of *air bubbles*.

During the procefs of impregnating water with air, by diffolving lead ore in the acid of vitriol, a part of the glafs tube was coated with a thin pellicle of fulphur, which had accompanied the air in its afcent: May not the fulphur fublimed from Harrowgate water, have accompanied the air which gives it its fmell? Is it certain that *this kind of air* does not confift of attenuated parts of fulphur, which have acquired an elaftic force, and which cannot be condenfed in water? Or is it not more probable, that this kind of air is one

of

of the conſtituent parts of ſulphur, than ſulphur itſelf? Does this air, and the inflammable air ſeparable from ſome metallic ſubſtances, by ſolution in acids, conſiſt of *oleaginous* particles in an elaſtic ſtate?

If the reader wiſhes to impregnate common water with the ſulphureous properties of Harrowgate water, he may do it in the following ſimple manner:—Into an apothecary's vial, holding four or five ounces, put ſome pounded lead ore, and pour upon it ſome acid of vitriol (there is no occaſion to be ſolicitous about the proportions of the lead ore and acid, for if there be more or leſs ore than the acid can diſſolve, ſtill air enough for the purpoſe will be diſcharged); wrap a few folds of wet linen round one end of a bended

tube, insert this end into the neck of the vial so closely, that no air may pass out of the vial except through the tube; the end of the tube should be at some distance from the surface of the acid. Put the other end of the tube into a bottle full of water, then, by setting the vial on the hot bar of a grate, or by some other means, heat the acid, and as soon as it is heated, it will begin to act on the lead ore, and a great quantity of air will be discharged, which will pass through the tube into the water in the bottle, and in a few minutes the water will be strongly impregnated with the sulphureous properties of Harrowgate water. Besides its sulphureous impregnation, Harrowgate water contains sea salt; and most other sulphureous waters

contain

contain ſome ſalt or other, ſo that to make a complete imitation of them, the ſalts which they ſeverally hold ſhould be added, in due proportion, to the water impregnated with the air here ſpoken of.

Though I am greatly diſpoſed to believe, that ſulphureous waters are impregnated with their peculiar ſmell and taſte, after the manner I have deſcribed; yet, to aſſiſt the reader's conjectures concerning the origin of this impregnation, I will mention another way in which it may be ſuppoſed to ariſe, and which will account for the ſaline taſte as well as the ſmell of the water.

I know not whether any ſpecies of maritime plants, containing ſea ſalt, will impregnate water with a ſulphureous ſmell by means of *putre-*

faction; nor whether all of them will do it by means of *combustion*, but that one of them will do it I can have no doubt: I allude to the *bladder fucus* or *sea wrack*, which is burned on our coasts for the making of *kelp*. It has been mentioned before *, that sea wrack, when burned to a black coal, will yield, by being boiled in water, a great quantity of common salt; and I would now remark, that the water extracts from the black ashes, not only a great quantity of common salt, but *something* else also, by which, without losing its transparency, it acquires both the smell and sulphureous taste of Harrowgate water; and by which it is enabled, like that water, to blacken silver and white paint.

That

* Vol. I. p. 137.

That *something* I am ſenſible may be what chemiſts call *liver of ſulphur*, or an union of ſulphur with fixed alkali, and it would not be difficult to explain its formation during the combuſtion of the ſea wrack; no ſulphur however can be precipitated from the water by the acid of vitriol, though that acid turns it, as is the caſe with Harrowgate water, a little cloudy. The air extracted from iron by the acid of ſea ſalt, impregnates water with a ſmell ſomewhat reſembling that of Harrowgate water, but its difference both from the natural and the artificial ſulphureous waters, may be eaſily diſtinguiſhed, eſpecially after the water has ſtood a few hours expoſed to the air.

ESSAY

ESSAY VII.*

OF DERBYSHIRE LEAD ORE.

LEAD ore, as dug out of the mine, is generally much mixed with ſpar, limeſtone, and other ſubſtances, bulk for bulk, lighter than the ore itſelf. It undergoes various dreſſings before it becomes a merchantable commodity, the general tendency of which is to free it, as much as poſſible, from every heterogeneous impurity.

Suppoſe

* The ſubſtance of this Eſſay was printed in the Philoſ. Tranſ. 1768.

Suppofe that a cubic foot of lead ore, which contained no fpar or other extraneous matter, would weigh 7800 ounces, and that a cubic foot of fpar, which contained no lead ore or other foreign fubftance, would weigh 2700 ounces, then would a mixture, confifting of a cubic foot of pure lead ore, and a cubic foot of pure fpar, weigh 10500 ounces, and one cubic foot of fuch a mixture would weigh 5250 ounces. It is obvious that, according to the different proportions in which the particular kinds of fpar and lead ore here affumed, are fuppofed to be mixed together, a cubic foot of the mixture will have different weights, the limits of which are on the one hand 7800, and on the other 2700 ounces; it never can weigh fo little as 2700 ounces, for then

then it would consist intirely of spar without any lead ore; nor can it ever weigh so much as 7800 ounces, for then it would consist intirely of lead ore without any spar.

From this view of the matter it is evident, that the purchasing of lead ore by the measure, which is the general, though not the universal custom in *Derbyshire*, is a mode liable to some exception; since a dish, containing any definite measure, must have different weights according as the ore with which it is filled is more or less free from spar. And it is scarce possible, by repeated dressings, to separate all the spar from an ore, or equal portions of it from equal portions of ore.

There is a diversity, however, in the weights of equal measures of lead

ore which, probably, does not arife from fparry or other heterogeneous accretions, but from the nature of the ore itfelf. I have carefully calculated the weight of a cubic foot of many of the Derbyfhire lead ores; the weight of a cubic foot of the lighteft which I met with was 7051 ounces, and the weight of a cubic foot of the heavieft was 7786 ounces; the difference amounting to between a ninth and a tenth part of the weight of the lighteft. There are, probably, other ores of lead, the weights of equal bulks of which differ more than thefe here mentioned; but the difference between thefe is fufficient to fhew the great uncertainty of purchafing lead ore by the meafure, fince ten difhes of one fort of ore may not weigh more than nine difhes

of

of another ſort, though both the ſorts are equally well dreſſed.

Lead ore is not always of the ſame goodneſs in the ſame mine, nor even in the ſame part of the ſame mine; and, what is more remarkable, the different parts of the ſame lump of ore have in equal bulks different weights. I could not eaſily have believed this, unleſs a variety of experiments had convinced me of the fact.

They were employed lately at *Holywell* in ſmelting a lead ore from the *Iſle of Man*; the ore was rich in ſilver. A lump of this ore, weighing about ten ounces, was broken into ſeveral pieces, and ſuch of the pieces were ſelected as appeared to the eye to be wholly pure. I eſtimated the weight of a cubic foot of ſix of thoſe pieces,

and found that a cubic foot of the lighteft kind would have weighed 6565 ounces, and a cubic foot of the heavieft kind would have weighed 7636 ounces. Suppofing the weight of a cubic foot of water, to be denoted by 1000, the mean weight of a cubic foot of the fix different pieces of this ore, may be expreffed by 7115 avoirdupoife ounces.

A very pure fpecimen of teffellated lead ore, from a mine near *Afhover* in *Derbyfhire*, was broken into fix pieces, weighing near one ounce each. A cubic foot of the lighteft of thefe pieces would have weighed 7326 ounces, and a cubic foot of the heavieft would have weighed 7786 ounces. The mean weight of a cubic foot of the fix pieces was 7566.

At

At the ſame mine they frequently meet with ſmall quantities of ſteel-grained lead ore. Six different pieces of the ſame lump of this kind of ore were choſen, each of which appeared quite free from ſpar and every other impurity. A cubic foot of the lighteſt of theſe pieces would have weighed 7188 ounces, and a cubic foot of the heavieſt would have weighed 7442 ounces. The mean weight of a cubic foot of the ſix pieces was 7342.

Other lumps of ore from different mines, were reſpectively broken into different pieces, and ſcarcely any two equal pieces of the ſame lump were obſerved to agree in weight. This diverſity in the weights of equal bulks of the ſeveral pieces of the ſame lump of ore may be owing,

either to the different proportions in which the conſtituent parts of the ore are combined in the ſeveral pieces; or to the different quantities of extraneous ſubſtances imperceptibly mixed with them; or, which ſeems moſt probable, to a diverſity in the ſize or configuration of their pores.

But be the cauſe of this diverſity what it may, the fact, I believe, is certain, and by no means ſingular; for not to mention the varieties obſervable in the weights of equal bulks of different pieces of roll brimſtone, of corroſive ſublimate, of caſt ſteel, and other factitious ſubſtances, the natural ſpars generally found along with lead ore are ſubject to a ſimilar diverſity, though not, perhaps, in an equal degree.

A piece of *rhomboidal*, otherways

called *refracting* or *lantern ſpar*, was broken into four ſmaller pieces, the weights of a cubic foot of each of which were 2675, 2687, 2715, 2723; the medium of the four is 2700 ounces. Mr. *Cotes* fixes the weight of a cubic foot of Iceland cryſtal at 2720, and *Wallerius* fixes it at 2700 ounces.

The weights of a cubic foot of four pieces of the ſame lump of *cubical ſpar* were 3204, 3218, 3222, 3231; the medium of the four is 3219 ounces.—Moſt of the ſpars met with in *Derbyſhire* are either *rhomboidal* or *cubical*; they are eaſily diſtinguiſhed from each other by a view of their ſhape, when their angles can be diſcerned; and when the ſhape cannot be eaſily ſeen, the nature of the ſpar may be aſcertained

 by

by touching it with an acid; the rhomboidal ſpar always effervefcing with an acid; and the cubical reſiſting its action. The lead ſmelters make great uſe of the cubical ſpar as a *flux* for ſuch lead ores as do not readily melt: it is curious to ſee its effect; a few ſhovels full of it, thrown upon a heap of red hot ore, immediately melting down the ore into a liquid, though the longeſt continuation of the ſame degree of heat, without the addition of the ſpar, would not have been ſufficient for the purpoſe.

Six ounces of fine teſſellated lead ore were put into a crucible and expoſed, at firſt, to a gentle, and afterwards to a ſtrong fire: the ore grew red, and emitted fumes which ſmelled of ſulphur; at length it melted, and

and the fumes became very copious; they were accompanied with a yellowish flame upon the surface of the melted ore, and when collected had a whitish appearance. The crucible after the ore had continued a full hour in perfect fusion, was taken from the fire, and when it was cold it was broken. The mass which it contained weighed five ounces and an half; there was no scoria observable on its surface, nor were any particles of metal formed; it was still an ore of lead.

The mass remaining from the last experiment was put into a fresh crucible, and exposed to a strong melting heat; the fumes which arose from it seemed to be heavy; they brooded over the surface of the melted mass in undulating flames, which

which now and then appeared like burning zinc *. The lead was now formed, and many particles of it were sublimed to at least six inches above the surface of the liquid in the crucible. After letting the crucible continue two hours in this state, I poured out its contents, and found them consisting partly of lead, partly of lead ore, and partly of a very minute portion of brownish scoria. I repeated this experiment with the same success.

These experiments prove, that some substance or other is contained in lead ore, which must be dispersed before the ore can be formed into lead; and they shew too, that it requires a considerable time to effect

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* It may deserve to be inquired whether zinc may not be contained in lead, iron, and other ores, more frequently than is supposed.

the diſperſion of this ſubſtance, ſince ſix ounces of ore, though kept three hours or more in complete fuſion, were not wholly brought into the form of lead; they inſtruct us alſo to believe that the lead in this kind of ore is in its metallic ſtate, as the ore was changed into lead without the addition of any ſubſtance containing the inflammable principle; and, laſtly, they render it probable, that the fumes ariſing from melted ore, carry off with them no inconſiderable portion of the lead itſelf. At the great ſmelting houſes in Derbyſhire, they put a ton of ore at a time into the furnace, and work it off in eight hours; the ore might be wholly melted in one hour, but the lead, perhaps, is not formed in the greateſt poſſible quantity in eight hours.

Some

Some fine teſſellated lead ore from Derbyſhire, was pounded into ſmall lumps, each about the ſize of a pea, and carefully picked from ſpar and other impurities. Sixteen ounces of this ore, thus previouſly cleanſed, were diſtilled in an earthen retort; as ſoon as the ore felt the fire, the ſtopple of the quilled receiver had a ſtrong ſmell, reſembling that of the inflammable air, ſeparable from ſome metals by ſolution in acids; ſoon after a ſmall portion of a liquid came over into the receiver; the fire was then raiſed till the retort was of a white heat, when a black matter began to be ſublimed into the neck of the retort; the operation was then diſcontinued. This experiment was undertaken with a view of ſeeing whe-

whether ſulphur could be ſeparated from lead ore, as it may be from ſome ſpecies of the pyrites, by diſtillation, and it appears from the iſſue of the experiment that it cannot, at leaſt in the degree of heat which is requiſite for ſubliming the ore. Upon breaking the retort, I found that the ore had been melted during the operation, for there was a conſiſtent cake of ore of the figure of the bottom of the retort; the weight of this cake was fifteen ounces and an half, the weight of the liquid in the receiver, and of the black matter which had been ſublimed, did not together amount to one quarter of an ounce, ſo that a quarter of an ounce or more had been diſperſed, probably in the form of air, or ſome elaſtic fluid. The ore by this proceſs

cefs had loft one thirty-fecond part of its weight. The liquid did not effervefce with either acids or alkalies; nor did it produce any change in the colour of blue paper; yet I am certain, from experiment, that one drop of oil of vitriol, though diluted with two ounces of water, would have produced a fenfible rednefs on the blue paper which I ufed. The liquid, notwithftanding, had an acid tafte, and a pungent fmell, refembling that of the volatile vitriolic acid. The black matter which had been fublimed into the neck of the retort, was examined with a microfcope, and it appeared to be pure lead ore. The melted ore which was found at the bottom of the retort, had not any appearance of fcoria, or of lead, upon its furface.

Some

Some phenomena attending this experiment deſerved, I thought, a further inveſtigation. I therefore diſtilled another 16 ounces of ore, but with a fire ſtronger and continued for a longer time than in the preceding experiment: the quantity of liquid was much the ſame, there was a ſmell of ſulphur, and, perhaps, to the amount of half a grain of ſulphur was found in the receiver; the ore was in this experiment ſublimed into the neck of the retort to the thickneſs of one fourth of an inch. There was found, as before, a cake of melted ore at the bottom of the retort, but no ſenſible portion of either *lead* or *ſcoria**; ſo that we may ſafely

* I have ſaid no ſenſible portion; there was, however, an appearance of ſcoria adhering to the ſide, and an appearance of lead adhering

ſafely conclude that lead ore cannot be decompoſed by the ſtrongeſt fires in cloſe veſſels, but that it may be ſublimed in them. The ore had loſt near an ounce of its weight.

Though the experiment is ſufficiently troubleſome, I was not deterred from making it once more; for I wanted to ſee whether lead ore could be wholly ſublimed; as I thought that philoſophers might thereby form ſome conjectures of the efficacy of ſubterraneous fires in ſubliming

adhering to the bottom of the retort; but the quantity of each was exceedingly ſmall, and they were both, probably, produced from that minute decompoſition of the ore which produced the ſulphur, and which would not, I think, have taken place in any degree, had there been no communication with the external air; but the orifice of the quilled receiver was not always cloſely ſtopped during the diſtillation.

in lead ores, and, perhaps, ores of other metallic ſubſtances. The event of this third experiment was perfectly correſpondent to that of the two former, with reſpect to the production of liquid, and the ſeparation of air, which was caught in a bladder, but was not found to be inflammable: the lead ore too was ſo plentifully ſublimed into the neck of the retort, that it quite plugged it up for above three inches in length. Upon diſcontinuing the fire which had been raiſed to a degree of heat exceedingly great, I found the retort was cracked, and that the cake at its bottom was very different from what was found at the bottom of the other retorts, which had ſtood the fire without cracking; for this cake was covered with a black glaſſy ſco-

ria ¼ of an inch in thickneſs, and the ore which laid under it, was in part changed into *lead*, and the whole of the ore did not weigh quite ten ounces, ſo that above ſix ounces had been loſt by eſcaping through the crack. By a communication with the air through the crack, the ore was decompoſed, and thus both *lead* and *ſcoria* were formed, which in the other experiments, for want of ſuch a decompoſition, could not be formed. There was a thin coat of ſulphur alſo which lined the inſide of the receiver, and this ſulphur, probably, aroſe from the decompoſition of the ore, ſince none, or next to none, was obſerved in the other diſtillations of the ore. I found that the weight of a cubic foot of the ore, which had been ſublimed into

the neck of the retort, was 7500 ounces; which sufficiently agrees with the weight I had before ascertained of this kind of ore. A cubic foot of the black glassy scoria weighed 3333 ounces; and the metallic cake which laid under it, and which consisted partly of lead, and principally of ore not quite changed into lead, gave 8738 ounces to the cubic foot.

Finding that sulphur could not be separated from lead ore by distilling it in close vessels without addition, and yet being much disposed to think that it contained a considerable portion of sulphur, I first thought of distilling it with charcoal dust, iron filings, sand and other additions; but recollecting that sulphur might be separated from antimony

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by folution in acids, I thought it not improbable, that it might be feparated from lead ore by the fame means, and the fuccefs of the following experiment abundantly juftified the conjecture.

Upon ten ounces of lead ore, cleanfed as in the preceding experiments, I poured five ounces of the ftrongeft fuming fpirits of nitre; this ftrong acid not feeming to act upon the ore, I diluted it with five ounces of water; a violent ebullition, accompanied with red fumes, immediately took place; the folution of the ore in this *menftruum* became manifeft, and when it was finifhed, there remained floating upon the furface of the *menftruum* a cake of fine yellow fulphur, perfectly refembling common fulphur.

I re-

I repeated this experiment a great many times, in order to aſcertain the quantity of ſulphur contained in lead ore, and ſeparable therefrom by ſolution in acid of nitre. The reſults of different experiments were ſeldom the ſame; the matter ſeparable from the ore by ſolution, after being repeatedly waſhed in large quantities of hot water, in order to free it from every ſaline admixture, ſometimes amounted to more, ſometimes to leſs than one-third of the weight of the ore. This matter may, for the ſake of diſtinction, be called crude ſulphur. Its apparent purity might induce a belief that it contained no heterogeneous mixture, yet the following experiments ſhew how much we ſhould be deceived in forming

 ſuch

ſuch a conjecture, and how rightly it is denominated crude ſulphur.

From one hundred and twenty parts, by weight, of lead ore, I obtained, by ſolution in acid of nitre, ſubſequent waſhing in hot water, and drying by a gentle fire, forty parts of a ſubſtance which looked like ſulphur: theſe forty parts were put on a red-hot iron, the ſulphur was made manifeſt by a blue flame and pungent ſmell. When the flame went out there remained upon the iron unconſumed, twenty-ſix parts of a greyiſh *calx*; the weight of the ſulphur which was conſumed muſt therefore have amounted to fourteen parts, or between one eighth and one ninth part of the weight of the ore. It has been obſerved, that the weight of the matter, ſeparable from lead ore

by

by ſolution in acid of nitre, ſome-times exceeded and ſometimes fell ſhort of, one third part of the weight of the ore; this variety, as far as I have been able to obſerve, does not extend to the quantity of ſulphur contained in a given quantity of ore, it depends upon the quantity of *calx* remaining after the burning of the ſulphur. Different lead ores will doubtleſs contain different quantities of ſulphur; but that the ſulphur contained in the lead ore which I examined, conſtitutes between one eighth and one ninth part of the weight of the ore, is a concluſion upon which, from a variety of experiments, I am diſpoſed to rely.

There are ſaid to be annually ſmelted in *Derbyſhire* about ten thouſand tons

of lead ore*; now if means could be inverted (which I think very possible) of saving the sulphur contained in ten thousand tons of ore, supposing that the ore should only yield one tenth of its weight of sulphur, though it unquestionably contains more, *Derbyshire* alone would furnish annually one thousand tons of sulphur, the value of which would annually be about fifteen thousand pounds. I mention this circumstance thus publicly, in hopes that the lead smelters may be induced to prosecute the subject. If the sulphur contained in the lead ore could be collected, it would not only be a lucrative business to the smelters, but a great saving to the nation. We at present

* This estimate is, I have reason to think, too high.

present import the sulphur we use, and the consumption of this commodity is exceeding great, in the making of gunpowder, in forming the mixture for covering the bottom and sides of ships *, and in a great variety of arts. The smelters need not be apprehensive lest the quality of the ore should be injured by extracting the sulphur. Eighteen hundred weight of ore, from which the sulphur has been extracted, will certainly yield as much lead as twenty hundred weight of ore, from which the sulphur has not been extracted, and it will, probably, yield more. Arsenic is extracted

* This mixture is made of one part of tallow, of one part of brimstone, and of three parts nearly of rosin. The tallow and rosin are melted together, and the brimstone is stirred into them ; 140 pounds of brimstone is enough for a vessel of 140 tons.

tracted from a particular ore in Saxony, by roasting the ore in a furnace, which has a long horizontal chimney; the chimney is large, has many windings and angles, that the arsenic vapour which arises from the ore may be the more easily condensed: the arsenic attaches itself like soot to the chimney, and is from time to time swept out. It is very probable, that by some such contrivance the sulphur contained in lead ore might be collected. The smelters call every thing sulphur which is volatilized during the roasting or fluxing of an ore; but none of those with whom I have conversed, had any notion that common sulphur could be separated from lead ore.

The greyish calx which remained upon

upon the iron after the ſulphur was conſumed, was put upon a piece of lighted charcoal; the heat of the charcoal being quickened by blowing upon it, a great number of globules of lead were formed upon its ſurface. From hence it appears, that this calx is not an unmetallic earth contained in the ore, which the acid of nitre could not diſſolve; but a calx of lead, probably produced by the violent action of the acid, and which, by the addition of phlogiſton, may be exhibited in its metallic form. The quantity of this calx depends much upon the action of the acid upon the ore; if that action is violent, the calx is in greater abundance than if it be moderate; and I am not certain whether the experiment might not be ſo managed,

managed, that there would be little or no calx remaining; that is, a given quantity of ore might be so dissolved in the acid of nitre, that nothing would remain undissolved except the sulphur. But I have not yet perfectly satisfied myself as to the constituent parts of lead ore. I am certain that it contains *lead*, and *sulphur*, a *liquid*, and *air*: of the existence of the three first there can be no doubt, from what has been said, and the air is rendered beautifully apparent by the following experiment.

Let some lead ore be reduced into a fine powder, put it into a narrow-bottomed ale glass, fill the glass three parts with water, drop into the water a portion of the strong acid of nitre, you may judge of the requi-

fite quantity by feeing the folution commence, and you will obferve the ore univerfally covered with bubbles of air, thefe will buoy the ore up in large tufts to the furface, and the air will continue to be feparated from the ore till the acid becomes faturated with the lead. The falt arifing from the union of the nitrous acid to the lead often appears cryftallized upon the furface of the menftruum in this experiment; and if, when the menftruum is in that ftate, a little frefh acid be added, the falt inftantly cryftallizes and falls down to the bottom of the glafs, the acid having abforbed the water which held it in folution. When lead is diffolved in the manner here mentioned, by a very diluted acid of nitre, there is no appearance of ful-

phur

phur upon the surface of the menstruum, there is found at its bottom a black matter, which is the sulphur.

But though lead, and sulphur, a liquid, and air *, are unquestionably constituent parts of lead ore, I do not take upon me to say, that they are the only constituent parts: it is well known, that during the smelting of lead ore, a third part or more of its weight is some how or other lost, since from one and twenty hundred weight of ore, they seldom obtain above fourteen hundred weight of lead. What is lost partly consists of a scoria which floats upon the surface of the lead during the operation of smelting, and partly of what

is

* I have separated inflammable air from lead ore by dissolving it in the acid of sea salt.

is ſublimed up the chimney and diſſipated in the air. The ſcoria, I apprehend, would be very little, even from a ton of ore, if the ore was quite free from ſpar: it is the ſpar which is mixed with the ore that conſtitutes the main portion of the ſcoria *. I have in my poſſeſſion a ſolid maſs of ſcoria, which accidentally flowed out from a ſmelting furnace, and which in colour and conſiſtency perfectly reſembles grey lime-ſtone; it receives a poliſh as fine as marble, and it might perhaps with advantage be caſt into moulds for paving ſtones, chimney pieces, and other mat-

* The ſpar without queſtion augments the quantity of the ſcoria, yet the lead ore, which appears to the eye to be quite free from ſpar, yields a conſiderable portion of a black glaſſy ſcoria, when urged with a ſufficient fire.

matters. It arises from the spar mixed with the ore, and, by the addition of cubical spar to the ore during its fusion, its quantity might be increased at no great expence, in any proportion. That part of the ore which is sublimed and dispersed in the air, consists partly of the sulphur which is decomposed, and partly of lead; this sublimed lead attaches itself in part to the sides of the chimney of the smelting furnace; the rest of it flies up into the air, from whence it falls upon the ground, poisoning the water and herbage upon which it settles. This sublimed lead might be collected either by making it meet with water, or with the vapour of water, during its ascent, or by making it pass through an horizontal chimney of a sufficient length.

It is not eaſy to determine with preciſion the quantity of this ſublimed lead; a general gueſs, however, may throw ſome light upon the ſubject. They uſually at a ſmelting houſe work off three tons, or ſixty hundred weight, of lead ore every twenty-four hours; the ſulphur contained in ſixty hundred weight of ore, we will ſuppoſe to be ſeven hundred weight, and the lead to be forty hundred weight; the air, liquid, ſcoria, and ſublimed lead muſt together, upon this ſuppoſition, amount to thirteen hundred weight; now, admitting three hundred weight of the thirteen to be ſublimed lead, it is evident that, could it be collected, there would be an annual ſaving at each ſmelting houſe of above fifty tons, which, ſuppoſing it to be

worth four pounds *per* ton, would amount to above two hundred pounds a year. The price, if not the quantity of lead sublimate, here assumed, is, probably, below the truth; but my end is answered in giving this hint to persons engaged in the smelting business.

The following experiments, though upon a different subject, may not be unacceptable to the lovers of chemistry, as I do not remember to have any where met with them.

It is commonly known, that the surface of melted lead becomes covered with a pellicle of various colours. I undertook some experiments in the course of last winter, with a view to ascertain the order in which the colours succeeded each other. The lead which lines the boxes

boxes in which tea is imported from China happening to be at hand, ſome of it was melted in an iron ladle; but I was much ſurpriſed to find that its ſurface, though it was preſently covered with a duſky pellicle, did not exhibit any colours. Imagining that the heat was not ſufficiently ſtrong to render the colours viſible, the fire was urged till the ladle became red hot, the calcined pellicle upon the ſurface of the lead was red hot alſo, but it was ſtill without colour. The ſame parcel of lead was boiled in a crucible for a conſiderable time; during the boiling a copious ſteam was diſcharged, and the ſurface of the lead, as is uſual, became covered with a half vitrified ſcoria. The lead which remained unvitrified was then examined, and it

 had

had acquired the property of forming a fucceffion of coloured pellicles, during the whole time of continuing in a ftate of fufion.

Another portion of the fame kind of lead was expofed to a ftrong calcining heat for a long time; the part which remained uncalcined did, at length, acquire the property of exhibiting colours fufficiently vivid.

Thefe experiments induced me to conclude, that the Chinefe lead was mixed with fome fubftance from which it was neceffary to free it either by fublimation or calcination, before it would exhibit its colours. It would be ufelefs to mention all the experiments which I made before I difcovered the heterogeneous fubftance with which I fuppofed the Chinefe lead was mixed. At laft I hit

hit upon one which ſeems fully ſufficient to explain the phenomenon. Into a ladle full of melted Derbyſhire lead, which manifeſted a ſucceſſion of the moſt vivid colours, I put a ſmall portion of tin, and obſerved, that as ſoon as the tin was melted, and mixed with the lead, no more colours were to be ſeen. I do not know precifely the ſmalleſt poſſible quantity of tin, which will be ſufficient to deprive a given quantity of lead of its property of forming coloured pellicles, but I have reaſon to believe that it does not exceed one five thouſandth part of the weight of the lead.

Derbyſhire lead, which has loſt its property of exhibiting colours by being mixed with tin, acquires it again, as is mentioned of the Chineſe

lead, by being expofed to a calcining heat for a fufficient time; the tin, it is fuppofed, being feparated from the lead by calcination, before all the lead is reduced to a calx.

Some calcined Chinefe lead was *reduced* to its metallic form by burning fome tallow over it. The *reduced lead* gave, when melted, coloured pellicles; the calx of tin, which we fuppofe to have been mixed with the calcined lead, not being fo eafily reducible as that of lead.

I find that *zinc* is another metallic fubftance which has the fame property as tin with refpect to the depriving lead of its power of forming coloured pellicles; but it does not, I think, poffefs this power in fo eminent a degree as tin. I put fmall portions of *bifmuth* alfo into melted lead,

lead, but the lead ſtill retained its quality of forming colours. I melted together ſome ſilver and lead, but the lead did not thereby loſe its power of forming colours. A little tin added to a mixture of lead and biſmuth, or to a mixture of ſilver and lead, immediately takes away from the reſpective mixtures the faculty of forming coloured pellicles.

This quality of tin has hitherto, as far as I know, been unobſerved; but every new fact, relative to the actions of bodies one upon another, ought to be recorded. The change, produced in lead by the admixture of a ſmall portion of tin, is much felt by the plumbers, as it makes the metal ſo hard and harſh, that it is not without difficulty they can caſt it into ſheet lead. If their old lead

 does

does not work ſo willingly, nor exhibit colours ſo readily, as new lead, they may refer the difference to the ſmall quantity of tin contained in the ſolder, from which old lead can ſeldom be thoroughly freed.

With reſpect to the order in which the colours ſucceed one another upon the ſurface of melted lead, it ſeems to be the following one; *yellow, purple, blue,—yellow, purple, green,—pink, green,—pink, green.* Upon exhibiting the bright ſurface of melted lead to the air, I have often obſerved theſe ten changes to follow one another in a more or leſs rapid ſucceſſion, according to the degree of heat prevailing in the lead. If the heat is but ſmall, the ſucceſſion ſtops before it has gone through all the changes: but with the greateſt heat

I did

I did not obſerve any further variation. All the colours are very vivid, and each ſeems to go through all the ſhades belonging to it before it is changed into the next in order.

The formation of theſe colours may be explained from what has been advanced by Sir *Iſaac Newton*, and illuſtrated by the very ingenious experiments of Mr. *Delaval*, relative to the ſize of the particles conſtituting coloured bodies.

ESSAY

ESSAY VIII.

OF THE SMELTING OF LEAD ORE, AS PRACTISED IN DERBYSHIRE.

THERE is a certain ſtandard of perfection in the exerciſe of every art, which is not always well underſtood; and after men do ſufficiently comprehend it, many ages often paſs away before they are fortunate or ingenious enough to attain it. To extract the greateſt poſſible quantity

quantity of metal, from any particular kind, and any definite quantity of ore, is a problem of great importance, whether it be confidered in a philofophical or a commercial light; yet he who fhould apply himfelf to the folution of it, with an expectation of being ufeful to mankind, muft take into confideration another circumftance, of as much importance as the quantity of metal to be extracted,—the expence attending the procefs. For it is obvious, that a great quantity of metal extracted at a great expence, may not produce fo much clear profit, as a lefs quantity procured at an eafier rate; there is a beneficial limit between the quantity to be obtained, and the expence attending the operation, which nothing but experience can afcertain.

It has been proved, by experiments made in *France*,* that lead ore, when ſmelted by a fire made of wood, yielded one tenth more lead, than in the ordinary method of ſmelting by means of pitcoal; yet pitcoal is ſo much cheaper than wood, in Derbyſhire, and moſt other parts of Great Britain, that the loſs of a tenth of the lead is, probably, more than compenſated, by the uſe of pitcoal inſtead of wood or charcoal. It is poſſible, perhaps, even with the uſe of pitcoal, by an alteration in the proceſs of ſmelting, to extract from every twenty tons of ore, one ton more of lead than is any where extracted at preſent; but whether the price of one ton of lead, would be

more

* Eſſais des Mines, par M. Hellot, Vol. II. p. 114.

more than sufficient to defray the extraordinary expence attending the alteration of the process, must be left to the decision of those who are interested in the success of such inquiries.

The art of smelting the ores of all metallic substances, was, probably, at first very imperfect in every part of the world; and this doubtless has been a reason, why the use of iron has every where been of a more recent date, than that of the other metals, since it requires the application of a much stronger fire to smelt the ores of iron, than those of any other metal.

We have no certain account when, or by whom, the several metals were discovered; *Wallerius* says, that, as far as he knew, *Pliny* was the first

who

who enumerated the *six metals:* *
Pliny may, probably, be the first
Natural Historian who mentioned
them, but they were certainly known
long before the age of Pliny, and
were mentioned both by *Homer*, and
by an author far more ancient than
Homer—*Moses*.—" Only the *gold*,
and the *silver*, the brass (*copper*), the
iron, the *tin*, and the *lead*, every thing
that may abide the fire, ye shall make
it go through the fire, and it shall be
clean." † From this testimony we
are certain that all the metals were
known, at least in the country of the
Midianites, above 1450 years before
the birth of Christ, or near 900 years
after

* — Primus (scil. Plinius) quantum mihi constat, sex metalla enumeravit. Walker, de Syst. Minera. p. 10.

† Numb. xxxi. 22.

after the deluge. When I ſay all the metals, I muſt be underſtood to mean, all thoſe which were anciently known; for *platina*, the ſeventh metal, has been but recently diſcovered, and is not yet brought into general uſe; and *quickſilver* or *mercury* is not admitted by mineralogiſts into the claſs of metals; though it has a good right to be admitted, ſince in a ſufficient degree of cold, it poſſeſſes the great characteriſtic property of a *metal*, as diſtinguiſhed from a *ſemi-metal*—*malleability*. This property of malleability, as conſtituting the criterion by which metals differ from ſemi-metals, is not over rigidly to be inſiſted on, ſince iron, when firſt fluxed from its ore, or when converted into ſteel, and hardened by being ſuddenly immerſed when red

hot

hot in water, is lefs malleable than *zinc*, which is always claffed amongft the femimetals.

It has been contended, that copper was one of the firft metals which was ufed as money, and that gold and filver were, in very remote ages, of little account in that view. In many inftances the greatnefs of the *Roman* name has made us forget the æra when that people began to be dif-tinguifhed in hiftory, and induced us to confider their cuftoms, as the firft which prevailed amongft man-kind. It is granted, that *Servius Tullius* firft coined copper, and that the Romans ufed no other currency till the four hundredth and eighty-fifth year of their city *, when filver began to be coined; but from this

* Plin. Hift. Nat. Lib. XXXIII. § 13.

conceſſion, no argument can be deduced for the ſole uſe of copper as a currency, in the firſt ages of the world. We know, from undoubted authority, that ſilver was uſed in commerce, at leaſt eleven hundred years before even the foundation of Rome.—*And Abraham weighed to Ephron, the ſilver which he had named in the audience of the ſons of Heth, four hundred ſhekels of ſilver, current money with the merchant* *. About 60 years before Abraham paid this ſum for a piece of land in *Canaan*, he is ſaid, upon his return from *Egypt*, to have been rich, not in copper and iron, but in ſilver and gold †.

Iron and copper were certainly known before the deluge; and it is probable, that all the other metals,

every

* Gen. xxiii. 16. † Gen. xiii. 2.

every one of which is more eaſily extracted from its ore than iron and copper are from theirs, were known alſo to the antediluvians; we have proof, however, that in the time of Abraham, gold and ſilver were eſteemed, as they are at preſent, precious metals; and hence it ſeems reaſonable enough to conclude, that *Noah* was able to inſtruct his deſcendants in the art of ſmelting metallic ores: but, though this be admitted, we need not be ſurpriſed at the ignorance of many barbarous nations in this particular. For the various colonies which, either by compulſion or choice, quitted the plains of *Aſia*, in ſearch of ſettlements, may not always have had in their company men who had been inſtructed in the art of ſmelting; and thoſe who

did underſtand it, when the colony firſt migrated, may, in many inſtances, have died before any ores were diſcovered, upon which they might have exerted their ſkill; and thus the art of ſmelting being once loſt, it is eaſy to conceive that many nations may have remained for ages without the uſe of metals, or with the uſe of ſuch only as are found ready formed in the earth, or are eaſily fluxed from their ores.

The earth in a little time after the deluge, and long before it could have been peopled by the poſterity of Noah, muſt have become covered with wood; the moſt obvious method of clearing a country of its wood, is ſetting it on fire: now in moſt mineral countries there are veins of metallic ores, which lie

con-

contiguous to the surface of the earth, and these having been fluxed whilst the woods growing over them were on fire, probably, suggested to many nations the first idea of smelting ores.

—— Pow'rful gold first raised his head,
And brass, and silver, and ignoble lead,
When shady woods, on lofty mountains grown,
Felt scorching fires; whether from thunder thrown,
Or else by man's design the flames arose.

—— ——

Whatever 'twas that gave these flames their birth,
Which burnt the towering trees and scorch'd the earth,
Hot streams of silver, gold, and lead, and brass, (copper)
As nature gave a hollow proper place,
Descended down and form'd a glitt'ring mass *.

 There-

* Lucretius by Creech, Vol. II. p. 572.

There is no natural abſurdity in this notion of the poet; and indeed it is confirmed by the teſtimony of various ancient hiſtorians, who ſpeak of ſilver and other metals being melted out of the earth, during the burning of the woods upon the *Alps* and the *Pyrenees*. A ſimilar circumſtance is ſaid to have happened in *Croatia* in the year 1761; a large maſs of mixed metal, compoſed of copper, iron, tin and ſilver, having been fluxed, during the conflagration of a wood, which was accidentally ſet on fire *.

The putting a quantity of ore upon a heap of wood, and ſetting the pile on fire, in conformity to the manner in which ores were melted during the burning of foreſts, was, it

* Annual Regiſter, 1761, p. 138.

it may be conjectured, the firſt rude proceſs by which metals were extracted from their ores. But as the force of fire is greatly diminiſhed, when the flame is ſuffered to expand itſelf, and as the air acts more forcibly in exciting fire, when it ruſhes upon it with greater velocity, it is likely, that the heap of wood and ore would ſoon be ſurrounded with a wall of ſtone, in which ſufficient openings would be left for the entrance of the air, and thus a kind of furnace would be conſtructed. The *Peruvians*, we are told, "had diſcovered the art of ſmelting and refining ſilver, either by the ſimple application of fire, or where the ore was more ſtubborn and impregnated with foreign ſubſtances, by placing it in ſmall ovens or furnaces on high

 grounds,

grounds, ſo artificially conſtructed that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted."*

This method of ſmelting ores on high grounds, without the aſſiſtance of a bellows, at leaſt of a bellows moved by water, ſeems to have been formerly practiſed in other countries as well as in *Peru*. When *M. Belon* travelled into *Greece*, he found the furnaces placed on the ſides of rivulets, and obſerves, that all their bellows played with wheels turned by ſtreams of water, yet formerly they had ſmelted their ores in a different manner:[e] for upon the mountains

* Robertſon's Hiſt. of America.—Alonſo Barba, Treatiſe of Metals, French Tranſlation. Vol. I. p. 272.

tains of *Macedonia*, where mines had been wrought in the time of *Philip* the father of *Alexander*, great heaps of ſlag have been diſcovered, which are ſituated ſo far above any river of the country, that the furnaces from which they were formed, muſt, probably, have been wrought by the wind. There are ſeveral places in *Derbyſhire* called *Boles* by the inhabitants, where lead has been anciently ſmelted, before the invention of moving bellows by water. Theſe places are diſcovered by the ſlags of lead, which are found near them; there is no certain tradition concerning the manner in which the ore was ſmelted at theſe boles; it was, probably, as ſimple as that of the *Peruvians*; for in *Derbyſhire*, as well as in *Peru*, they ſeem chiefly to have

relied

relied upon the ſtrength of the wind for the ſucceſs of the operation; the boles being always ſituated upon high grounds, and moſtly upon that ſide of a hill which faces the weſt. This ſituation was not fixed upon without deſign, ſince the wind blows in England, in the courſe of a year, near twice as many days from that quarter as from any other *. A method is mentioned by *Erckern* † of ſmelting biſmuth ore by the wind, and it ſeems as if the ore of lead might have been ſmelted at theſe boles,

* As may appear from the following abridged ſtate of the winds at London in the years 1774 and 1775.

	N	S	E	W	NW	SE	NE	SW	
1774	25	21	17½	24	43½	30	74	126½	days
1775	22½	21½	11	18½	39½	32½	72	148	

Philoſ. Tranſ. 1774—5.

† See Fleta Minor, by Sir John Pettus,

boles, after the ſame manner. This method conſiſts in putting the biſmuth ore, when beat to a proper ſize, into ſmall flat iron pans; theſe are ſet in a row contiguous to each other, in an open place, and when there is a ſtrong wind, a fire of dry wood is made cloſe to the pans, and on that ſide of them from which the wind blows; by this contrivance, the wind driving down the flame of the wood upon the pans, the ore contained in them is quickly melted. A pig of lead was dug up at one of the boles in the year 1766 on *Cromford* moor near *Matlock*; upon its under ſurface there is an inſcription in *relievo*, from which it appears to have been ſmelted in the age of the Emperor *Adrian*; it is not very different in ſhape from the pigs which

are caſt at preſent; it conſiſts of ſeveral horizontal layers of unequal thickneſſes, and there is an irregular hole in it running from the top to near the middle of its ſubſtance; from theſe appearances it ſeems as if it had been formed by pouring into a mould, at different times, ſeveral quantities of lead; and if lead had been ſmelted after the manner before mentioned of ſmelting biſmuth ore, the ſeveral pans being emptied, at different times as they became ready, into the ſame mould, would have yielded a maſs of lead divided into layers of unequal thickneſſes, and reſembling this Roman pig; for the hole in its ſurface was, probably, made accidentally, from the unequal cooling of the lead, or from ſome extraneous matter being lodged in it.

The

The boles in Derbyshire are, probably, many of them of high antiquity, as appears from the pig of lead before mentioned; yet I have met with a passage in a writer of the last century, from which it is evident that the method of smelting lead on high grounds was then practised in the Peak. "The lead-stones in the Peak lie but just within the ground next to the upper crust of the earth. They melt the lead upon the top of the hills that lie open to the west wind; making their fires to melt it as soon as the west wind begins to blow; which wind by long experience they find holds longest of all others. But, for what reason I know not, since I should think lead were the easiest of all metals to melt, they

they make their fires extraordinary great." *

The ſmelting of ore by the variable and uncertain action of the wind, muſt have been a troubleſome proceſs. It has therefore been univerſally diſuſed, and the more regular blaſt of a bellows has been introduced in its ſtead. The invention of the bellows is attributed by *Strabo* to *Anacharſis* the Scythian: † but it is more probable, that he was the inventor of ſome improvement of this machine, than of the machine itſelf; for *Homer*, who lived long before the age of *Anacharſis*, deſcribes *Vulcan* as employing twenty pair of bellows at once, in the formation of *Achilles*'s ſhield.

* Childrey's Britan. Bacon, 1661.
† Strab. Geog. Lib. VII.

ſhield.* It is difficult to ſay when the art of moving bellows, by means of a water wheel, was firſt diſcovered; it is pretty certain, that the ancients did not know it; and that it was very generally known, amongſt the Germans at leaſt, in the time of Agricola, one of the firſt of our metallurgic writers, for he ſpeaks of it in ſeveral places without any hint of its being a recent invention.† The heat of the fire in a furnace depending much upon the force of the blaſt of air impelled againſt the fuel; and that force, other circumſtances remaining the ſame, being in proportion to the quantity and velocity of the air; the application of a power able

* Iliad. Lib. XVIII. v. 470.

† Agric. de Re Metal. publiſhed in 1550. p. 165. 338.

able suddenly to compress the largest bellows when swelled with air, could not fail of being considered by metallurgists, as an invention, whenever it was made, of the last importance. The moderns accordingly have, in many instances, worked over again, with considerable profit, the heaps of iron and other kinds of slag, from which the metal had been but imperfectly extracted, before the moving of bellows by water was discovered.

It is not fifty years since the *blast* or *hearth* furnace, was the only one in use for smelting lead ore in *Derbyshire*. In this furnace ore and charcoal, or ore and what they call white coal, which is wood dried but not charred, being placed in alternate layers, upon a hearth properly

con-

conſtructed, the fire is raiſed by the blaſt of a bellows, moved by a water wheel; the ore is ſoon ſmelted by the violence of the fire, and the lead as it is produced trickles down a proper channel, into a place contrived for its reception. There are not at preſent, I believe, above one or two of theſe *ore hearths* in the whole county of Derby; this kind of furnace, however, is not likely to go entirely out of uſe, ſince it is frequently applied to the extracting lead from the *ſlag* which is produced, either at the *ore hearth*, or the *cupola* furnace, and it is then called a *ſlag hearth*; and the lead thus obtained is called *ſlag lead*: the fire in a ſlag hearth is made of the cinder of pitcoal, inſtead of charcoal.

The furnace called a *cupol* or *cu-*

pola, in which ores are ſmelted by the flame of pitcoal, is ſaid to have been invented about the year 1698, by a phyſician named *Wright* *, though Beccher may, perhaps, be thought to have a prior claim to its invention or introduction from Germany †. But whoever was the firſt inventor of the cupola, it is now in general uſe, not only in Derbyſhire and other counties, for the ſmelting of the ores of lead, but both at home and abroad, where it is called the Engliſh furnace, for the ſmelting of copper ores. This furnace is ſo contrived, that the ore is melted, not by coming into immediate contact with the fuel, but by the reverberation of the flame upon it. The bottom of the furnace on which the lead

* Eſſais des Mines, Vol. II. p. 114.

† See Vol. I. p. 33.

lead ore is placed, is ſomewhat concave, ſhelving from the ſides towards the middle; its roof is low and arched, reſembling the roof of a baker's oven; the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free acceſs; at the other end oppoſite to the fire-place, is a high perpendicular chimney; the direction of the flame, when all the apertures in the ſides of the furnace are cloſed up, is neceſſarily determined by the ſtream of air which enters at the grate, towards the chimney, and in tending thither it ſtrikes upon the roof of the furnace, and being reverberated from thence upon the ore, it ſoon melts it.

It is not always an eaſy matter to meet with a current of water ſuffi-

cient to move the bellows required in ſmelting on an hearth furnace; and to carry the ore from the mine where it is dug to a conſiderable diſtance to be ſmelted, is attended with great expence; this expence is ſaved by ſmelting in the cupola furnace, which not requiring the uſe of bellows, may be conſtructed any where. Wood is very ſcarce in every mining county in England; and though pitcoal coſts ten or twelve ſhillings a ton in Derby-ſhire, yet they can ſmelt a definite quantity of ore in the cupola, at a far leſs expence by means of pit-coal than of wood. — The flame which plays upon the ſurface of the ore and ſmelts it in a cupola fur-nace, is not driven againſt it with much violence; by this means

ſmall

ſmall particles of ore, called *bel-land*, may be ſmelted in a cupola furnace with great convenience, which would be driven away, if expoſed to the fierce blaſt of a pair of bellows in a hearth furnace. —Theſe are ſome of the advantages attending the uſe of a cupola in preference to a hearth furnace; and to theſe may be added one ſuperior to all the reſt,—the preſervation of the workmen's lives; the noxious particles of lead are carried up the chimney in a cupola, whilſt they are driven in the face of the hearth ſmelter at every blaſt of the bellows.

They generally put into the cupola furnace a ton of ore, previouſly beat ſmall and properly dreſſed, at one time; this quantity they call a *charge*; if the ore is very poor in lead, they put in ſomewhat more, and they

work off three charges of ore in every twenty-four hours. In about ſix hours from the time of charging the ore becomes as fluid as milk. Before the ore becomes fluid, and even whilſt it continues in a ſtate of fuſion, a conſiderable portion of its weight is carried off through the chimney; what remains in the furnace conſiſts of two different ſubſtances,—of the lead, for the obtaining of which the proceſs was commenced,— and of the *ſlag* or *ſcoria*. The proportion between theſe parts is not always the ſame, even in the ſame kind of ore; it depending much upon the management of the fire. The lead, being heavier than the ſlag, ſinks through it as it is formed, and ſettles into the concavity of the bottom of the furnace. The pure ſlag, accord-

according to the idea here given, is that part of the ore of lead which is neither driven off by the heat of the furnace, nor changed into lead. In order to obtain the lead free from the flag which swims over it, the smelters usually throw in about a bushel of lime; not, as is usually supposed, in order to contribute towards the more perfect fusion of the ore, but to dry up the flag which floats upon the surface of the lead, and which, being as liquid as lead, might otherwise flow out along with it. The flag being thus thickened by an admixture of lime, is raked up towards the sides of the furnace, and the lead is left at the bottom. There is a hole in one of the sides of the furnace, which is properly stopped during the smelting

of the ore; when the slag is raked off, this hole is opened, and being situated lower than the lead in the furnace, the lead gushes through it into an iron pot placed contiguous to the side of the furnace; from this pot it is laded into iron moulds, each containing what they call a pig of lead; the pigs, when cold, being ordinarily stamped with the maker's name, are sold under the name of *ore lead*. After the lead has all flowed out of the furnace, they stop up the tap hole, and drawing down the slag and lime into the middle of the furnace, they raise the fire till the mixture of slag and lime, which they simply term slag, is rendered very liquid; upon this liquid mass, they throw another quantity of lime to dry it up as in the former

part

part of the proceſs. This ſecond mixture of ſlag and lime is then raked out of the furnace, and the ſmall portion of lead ſeparated from the fuſion of the firſt, generally to the amount of twenty or thirty pounds, being let out of the furnace, a new charge of ore is put in, and the operation re-commenced. In order to ſpare the lime, and the expence of fuel attending the fluxing of the mixture of lime and ſlag, they have in ſome furnaces lately contrived a hole, through which they ſuffer the main part of the liquid ſlag to flow out, before they tap the furnace for the lead; upon the little remaining ſlag they throw a ſmall portion of lime, and draw the mixture out of the furnace without ſmelting it. This kind of fur-

furnace they have nick-named a *Maccaroni*.

The proceſs of ſmelting here deſcribed, appears to be defective in ſome points, which I will take the liberty to mention, and at the ſame time ſuggeſt the means of improvement; without, however, preſuming to ſay, how far it may be expedient to adopt the propoſed alterations; being ſenſible that what may appear very feaſible in theory, or may even anſwer in ſmall aſſays, may not be practicable in large works.

The firſt alteration which I would propoſe to the conſideration of the lead ſmelters, is to ſubſtitute an horizontal chimney of two or three hundred yards in length, in the place of the perpendicular one now in uſe. In the preceding Eſſay, which

which was first published in 1778, mention is made of the probability of saving a large quantity of sublimed lead, by making the smoke which rises from the ore pass through an horizontal chimney, with various windings to condense the vapour. I have since conversed with some of the principal lead smelters in *Derbyshire*, and find that I had over-rated the quantity of this sublimed lead; the weight of the *scoria* from a ton of ore, amounting to more than I had supposed; they were all of them, however, of opinion, that the plan I had proposed for saving the sublimate, was a very rational one. But so difficult is it to wean artists from their antient ways of operating, that I question very much whether any of them

would

would ever have adopted the plan they approved, if an horizontal chimney, which was built a little time ago in *Middleton Dale*, for a quite different purpose, had not given them a full proof of the practicability of saving the sublimate of lead, which is lost in the ordinary method of smelting. This chimney was built on the side of an hill to prevent some adjoining pastures from being injured by the smoke of the furnace. It not only answers that end, but it is found also to collect considerable quantities of the lead, which is sublimed during the smelting of the ore; this sublimed lead is of a whitish cast, and is sold to the painters at ten or twelve pounds a ton; it might perhaps be converted into red lead with still more profit.

A se-

A ſecond circumſtance to be attended to in the ſmelting of lead ore, is the ſaving the ſulphur contained in it. The pure lead ore of Derbyſhire contains between an eighth and a ninth part of its weight of ſulphur; but as the ore which is ſmelted is never pure, being mixed with particles of *ſpar*, *cawk*, *limeſtone*, *brazil*, and other ſubſtances, which the miners call *deads*, we ſhall be high enough in our ſuppoſition, if we ſay that the ordinary ore contains a tenth of its weight of ſulphur; it may not, probably, contain ſo much, but even a twelfth part, could it be collected at a ſmall expence, would be an object of great importance to the ſmelter. In the common method of ſmelting lead ore there is no appearance of the ſulphur it contains,

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it is confumed by the flame of the furnace, as foon as it is feparated from the ore; an attentive obferver may, indeed, by looking into the furnace, diftinguifh a diverfity in the colour of the flame, at different periods of the procefs; during the firft three or four hours after the ore is put into the furnace, the flame has a bluifh tint, proceeding no doubt from the fulphur which, in being fublimed from the ore, is inflamed: after all the fulphur is feparated from the ore, the flame has a whitifh caft, and then, and not before, the fire may be raifed for finifhing the operation; for if the fire be made ftrong before the fulphur be difperfed, the quantity of lead is lefs, probably, for two reafons; the fulphur unites itfelf in part to the lead which

is

is formed, and by this union becomes inseparable from it; for the sulphur cannot without much difficulty be separated from an artificial mixture of lead and sulphur, when the two ingredients have been fused together.—2. The sulphur, whilst it continues united to the lead in the natural ore, renders the ore volatile, so that in a strong heat a great portion of it is driven off. Hence, very sulphureous ores should be roasted for a long time with a gentle heat, and in this proper management of the fire, principally consists the superiority of one smelter above another.

An old lead smelter informed me that he had often reduced a ton of ore to 16 hundred weight by roasting it, but that he did not obtain more

more metal from it by a ſubſequent fuſion, than if he had fluxed it without a previous roaſting. This may be true of ſome ſorts of ore, but it is not true of very ſulphureous ores. Indeed the fire may be ſo regulated in a cupola furnace, as to make it anſwer the purpoſe of a roaſting and a ſmelting furnace at the ſame time. I have ſeen much lead loſt by ſmelting a ton of ſulphureous ore in eight hours, which might have been ſaved, if the fire had at firſt been kept ſo gentle as to have allowed twelve hours for finiſhing the operation.

Sulphur cannot be ſeparated from lead ore in cloſe veſſels, and the lead ore melts with ſo ſmall a degree of heat, that there may be more difficulty in procuring the ſulphur from the ores of lead, than from thoſe of

copper

copper or iron, however, I am far from thinking the matter impracticable, though I have not yet hit upon the method of doing it; and the following reflections may, perhaps, tend to supersede the necessity of collecting the sulphur in substance.

When it is said that the sulphur is consumed by the flame of the furnace as soon as it is separated from the ore, the reader will please to recollect, that sulphur consists of two parts,—of an inflammable part, by which it is rendered combustible, —and of an acid part, which is set at liberty, in the form of vapour, during the burning of the sulphur. Now this acid, though it may be driven out of the furnace in the form of a vapour, yet it is incapable of being thereby decomposed; it still

continues to be an acid; and, could the vapour be condensed, might answer all the same purposes as the acid of vitriol; since all the acid of vitriol, now used in commerce, is actually procured from the burning of sulphur. That the fact, with respect to the acid not being decomposed, is as I have stated it, may be readily proved. The smoke which issues out of the chimney for some hours after each fresh charge of ore, has a suffocating smell, perfectly resembling the smell of burning brimstone; and if a wet cloth, or a wet hand, be held in it for a very short space of time, and afterwards applied to the tongue, a strong acid will be sensibly perceived. Various methods may be invented for condensing this acid vapour, and, probably,

more commodious than the following one, which, however, I will juſt take the liberty of mentioning, as, if it ſhould not ſucceed, the trial will be attended with very little expence.

Suppoſing then an horizontal chimney to be built, let the end fartheſt from the fire be turned up by a tube of earthen ware, or otherwiſe, ſo that the ſulphureous acid may iſſue out in a direction parallel to the flue of the chimney, and at the diſtance of about a foot and an half above it. Let a number of large globular veſſels be made of either glaſs or lead; each of theſe globes muſt have two necks, ſo as to be capable of being inſerted into one another; let theſe veſſels be placed on the flue of the chimney, the neck of the firſt being inſerted into the

the tube through which we have ſuppoſed the ſulphureous acid to iſſue, and the neck of the laſt being left open, for fear of injuring the draught of the furnace. Let each of theſe globular veſſels contain a ſmall quantity of water, then it is conceived, that the heat of the flue will raiſe the water into vapour, and that this watery vapour will be the means of condenſing the ſulphureous acid vapour, if not wholly, at leaſt in ſuch a degree as may render the undertaking profitable. When the ſulphur is all conſumed, the draught of the furnace may be ſuffered to have its ordinary exit at the end of the horizontal chimney, by a very ſlight contrivance of a moveable damper. Since the firſt publication of the preceding Eſſay, I have ſeen an

an horizontal chimney at the copper works near Liverpool, where every thing I had said concerning the probability of saving sulphur by roasting lead ore, is verified with respect to copper ore; and I believe a patent has been granted to some individual for this mode of collecting sulphur. Sulphur might be obtained with equal facility from the *pyrites* which is found amongst coal, and this application of the pyrites might, probably, be more lucrative than the present one—making green vitriol*.

A third circumstance, which requires the utmost care of the lead smelter, is the leaving as little lead as possible in the slag. Near every smelting house there are thousands of tons of slag, which, when properly

* Vol. I. p. 229.

aſſayed, are found to yield from one eighth to one tenth of their weight of lead, though no perſon has yet diſcovered a method of extracting ſo much from them when ſmelted in large quantities; and indeed the ſmelters are ſo little able to obtain all the lead contained in them, that in many places they never attempt to extract any part of it: in ſome places where they do attempt it, I have known the proprietor of the ſlag allow the ſmelters 20s. for every pig of lead they procured of the value of 38s. beſides furniſhing them with fuel: and yet the men employed in ſuch an unwholeſome buſineſs, ſeldom made above 7s. a week of their labour. This fuſion of the ſlag of a cupola furnace is made, as has been mentioned, at a hearth furnace;

nace; the coal cinder, which they uſe as fuel, and the ſlag, are ſoon melted by the ſtrong blaſt of the bellows into a black maſs, which, when the fire is very ſtrong, becomes a perfect glaſs; this black maſs, even in its moſt liquid ſtate, is very tenacious, and hinders many of the particles of lead from ſubſiding; and it being from time to time removed from the furnace, a conſiderable quantity of lead is left in it, and thereby loſt. A principal part of the lead contained in the ſlag of the cupola furnace, is not, I apprehend, in the form of a metal, but in the form of a litharge or calcined lead: a portion of the lead, in being ſmelted from its ore, is calcined by the violence of the fire; this calcined lead is not only very vitrifiable of itſelf, but it

helps to vitrify the ſpar which is mixed with the ore, and thus conſtitutes the liquid ſcoria; might it not be uſeful to throw a quantity of charcoal duſt upon the liquid ſcoria in the cupola furnace, in order that the calcined lead might be converted into lead by uniting itſelf to the inflammable principle of the charcoal? —Iron will not unite with lead, but it readily unites with ſulphur, and, when added to a mixture of lead and ſulphur, it will abſorb the ſulphur, leaving the lead in its metallic form; might it not be uſeful to flux ſulphureous lead ores in conjunction with the ſcales or other refuſe pieces of iron, or even with ſome ſorts of iron ore? —— The ſmelter's great care ſhould be to extract as much lead as poſſible at the firſt

firſt operation of ſmelting the ore, and to leave the ſlag as poor as poſſible; but if he ſhould ſtill find either the ſlag of the cupola furnace, or that of the hearth furnace, containing much lead (as that even of the hearth furnace certainly does), he may, perhaps, find it worth his while to reduce the ſlag into a powder by a ſtamping mill, or by laying it in highways to be ground by the carts, or by ſome other contrivance, and then he may ſeparate the ſtony part of the ſlag from the metallic, by waſhing the whole in water, inaſmuch as the metallic part is far heavier than the other.

I eſtimated the weights of ſeveral pieces of ſlag, and found them to differ very much from each other; this difference is principally to be at-

attributed to the different quantities of lead left in them.

Weight of a cubic foot of

	Avoir. oz.
Slag from a cupola furnace, where no lime was used - - - - -	3742
Black slag from a hearth furnace - -	3652
Another piece - - - - - - -	3612
Black slag from another hearth furnace---struck fire with steel -	3378
Black glass-slag - - - - - -	3371

This may not be an improper place to add a word or two concerning the *Derbyshire Toadstone*, which constitutes one of the principal strata in the mining country*, and which is supposed to have been in its origin a *slag* thrown out by a *volcano*. It perfectly resembles some of the specimens, I have seen, of one of the sorts of the *lava* of *Vesuvius*, not only in

* See Vol. II. p. 206.

in the hardneſs of its texture, and blackneſs of its colour, but in its weight; a cubic foot of ſome ſorts of Derbyſhire toadſtone weighing more, and of other leſs than a cubic foot of the Veſuvian lava, which it reſembles. The ſtreets of *London* have ſome of them been paved, of late years, with a *toadſtone* from *Scotland*, of the ſame nature as the Derbyſhire toadſtone; and the ſtreets of *Naples* have for many centuries paſt been paved with the lava from Veſuvius which reſembles toadſtone. Neither the Derbyſhire toadſtone, nor that ſort of Veſuvian lava which reſembles it, ſeem to have experienced in their formation any great degree of heat; they are but in a half vitrified ſtate: the toadſtone I have frequently melted in a ſmith's forge

into

into a black glaſs, and the Veſuvian lava gives a glaſs of the ſame kind. The air has a manifeſt action upon the Derbyſhire toadſtone, for it not only waſtes away the ſpar which is found in the blebs of ſome ſorts of toadſtone, but it reduces into a browniſh mould, fit for vegetation, the moſt hard and compact ſorts; the Veſuvian lava is ſubject to the ſame change from the operation of the ſame cauſe.

Weight of a cubic foot of

	Avoir. oz.
Toadſtone hard and free from blebs -	2884
Veſuvian lava reſembling toadſtone -	2865
Iron ſlag, a greeniſh glaſs - - - - -	2843
Iron ſlag, a browniſh glaſs - - -	2729
Iceland cryſtal---Mr. Cotes - - -	2720
Toadſtone, decaying - - - - - -	2680
Another piece - - - - - - -	2662
Another piece - - - - - - - -	2558

ESSAY

ESSAY IX.

OF SILVER EXTRACTED FROM LEAD.

WE have no ſilver mines, properly ſpeaking, in *Great Britain*, but we have plenty of lead, from which ſilver is, in ſome places, extracted with much profit. If the method of doing this had been known to the ancient *Britons*, it might have freed our country from the reproach of *Cicero*, who tells his friend *Atticus*, that there was not a ſcruple of ſilver

in

in the whole iſland* ; and in another place, he ſays, that he had heard there was neither gold nor ſilver in *Britain*†. The *Romans* had a very imperfect knowledge of this country in the time of *Cicero*, ſo that his account of the matter may not, perhaps, deſerve to be much relied on; we are certain, at leaſt, that about fifty or ſixty years afterwards, both gold and ſilver were reckoned by *Strabo* amongſt the products of *Britain*‡: hence, if the Britons did not underſtand the art of extracting ſilver from lead at the firſt invaſion of the

* —— etiam illud jam cognitum eſt, neque argenti ſcrupulum eſſe ullum in illa inſula (Britann.) Epiſt. ad Att. L. IV. E. XVII.

† Epiſt. Fam. L. VII. E. VII.

‡ L. IV. p. 305.—See alſo Tacitus's Life of Agricola.

the Romans, they foon learned it from their conquerors; and this becomes more probable, if it be admitted, that filver was coined in Britain in the time of *Auguftus**.

Silver is fo commonly contained in lead, that it is efteemed a very great curiofity to meet with lead which is intirely free from it: it has even been afferted, that there is no lead in the world, except that of *Villach* in *Carinthia*, which does not contain filver†.

The more ancient alchemifts, not knowing, probably, that filver was fo generally contained in lead, and yet

* Sir John Pettus' Fod. Reg.

† Il n'y a point de plomb au monde, hormis celui de Villach, qui ne contient de l' argent. Lehman fur les Mines, Vol. I. p. 174.—See alfo Philof. Tranf. for 1665, p. 10.

yet obſerving that lead, when treated according to their proceſſes, often gave a portion of ſilver, were of opinion, that they could convert lead into ſilver*. This was an eaſy miſtake, and if they had obtained a portion of gold, they would, no doubt, have concluded, that they had tranſmuted the lead into gold; ſince there is no metal, perhaps, which does not *contain* a ſmall quantity of gold, or from which gold may not be *ſeparated* by long calcination.

Liſter had long ago obſerved, that all the Engliſh lead contained ſilver; and he ſpeaks as having, by his own experiments, proved the exiſtence of ſilver in the lead of at leaſt thirty different mines †; nor has any per-

ſon

* Gebri Chem. L. I. C. XIX.

† Liſter de Fontibus, Cap. II. S. 9, 10.

ſon ſince his time, found lead wholly free from ſilver. The *Derbyſhire* lead has been ſaid to contain two grains of ſilver in a pound of lead*. Every general obſervation of this kind is liable to much contravention from particular facts; becauſe the quantity of ſilver contained in lead, is not only different according as the lead is fluxed from the ore of different mines, but it is very poſſible in an aſſay of the ore of the ſame mine to meet with one piece of ore which ſhall afford a lead yielding eight or ten times as much ſilver as another piece would do. This diverſity ariſes from the ore itſelf being variable in quality in different parts of the ſame mine; and even different lumps of ore, though contiguous to each other, will

* Oper. Min. Explicata, p. 263.

will often yield very different quantities of silver, from the same quantity of lead. This observation may explain the reason of the very opposite testimonies, which have been sometimes given in courts of justice, concerning the richness of a mine from particular assays; the plaintiffs and defendants, where the issue to be tried was the quantity of silver, having been severally interested in getting the best and the worst pieces of ore assayed, in order to support their respective claims. There was a notable instance of this with respect to the lead mine of *Est-kyr-kyr* in *Cardiganshire*, which was discovered in 1690. The law at that time adjudged every mine to be a *royal mine* the metal of which contained enough of gold or silver to compensate the charges

charges of refining, and the loſs of the baſer metal in which they were contained. In conſequence of this law, the patentees of royal mines laid claim to the mine of *Eſt-kyr-kyr*, which was rich in ſilver, and they produced proof in *Weſtminſter-hall*, that the lead of that mine contained to the value of ſixty pounds of ſilver in every ton; whilſt the proprietor produced proof, that it only contained to the value of four pounds of ſilver in a ton*.

I have been informed by an intelligent perſon, that there are ſome lead ores in Great Britain, which, though very poor in lead, contain between three and four hundred ounces of ſilver in a ton of the lead. It is not to be expected that the proprietors

* Some Account of Mines, p. 27.

prietors of these, or of any other mines rich in silver, should be forward in declaring to the world the quantity of silver which they contain. The proprietor indeed of a lead mine containing silver, may work the same, without any apprehension of its being taken from him, under the pretence of its being a *royal mine*; yet the crown, and persons claiming under it, have the right of pre-emption, of all the ore which may be raised. There was an act of parliament passed in the sixth year of *William* and *Mary*, intitled,—An act to prevent disputes and controversies concerning royal mines.—This act gave great quiet to the subject, by declaring, that every proprietor of a mine of copper, tin, iron, or lead, should continue in possession

of

of the ſaid mine, notwithſtanding its being claimed as a royal mine, from its containing gold or ſilver: but it further enacted, that their majeſties, their heirs and ſucceſſors, and all claiming under them, ſhould have the privilege of purchaſing all the ore which ſhould be raiſed out of ſuch a mine, at the following prices; that is to ſay, paying for all ore waſhed, made clean, and merchantable, wherein is copper, after the rate of ſixteen pounds a ton; for tin ore (except that raiſed in Devonſhire and Cornwall) forty ſhillings; for iron ore forty ſhillings; and for lead ore nine pounds a ton. This ſtandard price of nine pounds a ton for lead ore was, at the time it was fixed, much higher than the ordinary price of ore, in which there was no ſilver

ſilver worth extracting; the beſt kind of Derbyſhire lead ore being, at preſent, generally worth no more than ſeven pounds à ton. It may deſerve, however, the conſideration of the legiſlature, whether the clauſe in the forementioned act, reſpecting the right of pre-emption, ſhould not be wholly repealed; as there may be many lead mines in England very rich in ſilver, but which, on account of the difficulty of working them, cannot be entered upon with advantage, whilſt this right ſubſiſts. At many lead mines, moreover, there are large quantities of ſteel-grained ore raiſed together with the ordinary ſort; now it generally happens that the ſteel-grained ore is much richer in ſilver than the ordinary diced ore of Derbyſhire; and it might, if ſepa-
rated

rated from the reſt, be worked for ſilver; but whether from an apprehenſion of the operation of the clauſe we are ſpeaking of, or from mere ignorance or inattention, all the ſorts of ore are mixed and ſmelted together.

Silver has formerly been extracted from lead in a great many places in this iſland. In the reign of Edward I, near 1600 pounds weight was obtained, in the courſe of three years, from a mine in *Devonſhire*, which had been diſcovered towards the beginning of his reign; this mine is called a ſilver mine by the old writers, but it appears to have been a mine of lead which contained ſilver *. The lead

* Hollingſhed's Chron. Vol. II. p. 316. See alſo, in the ſame author, a further account of

lead mines in *Cardiganshire* have at different periods afforded great quantities of silver: Sir *Hugh Middleton* is said to have cleared from them two thousand pounds a month*, and to have been enabled thereby to undertake the great work of bringing the new river from *Ware* to *London*; and in allusion, probably, to these two great circumstances of his life, there are painted upon some of his pictures the two terms—*fontes*—*fodinæ*. These same mines yielded, in the time of the great rebellion, eighty ounces of silver out of every ton of lead, and part of the king's army was paid with this silver, which was

of silver extracted from the lead in Devonshire and Cornwall in the time of Edward III. p. 413.

* Oper. Min. Explic. p. 245.

was minted at *Shrewsbury**. A mint for the coinage of Welch silver had before that time been established in 1637 at *Aberystwith*; the indenture was granted to *Thomas Bushel* for the coining of half-crowns, shillings, six-pences, two-pences, and pennies, and the monies were to be stamped with the ostrich feathers on both sides †. In the year 1604 near three thousand ounces of this Welsh bullion were minted, at one time, at the Tower ‡. *Webster*, in his History of Metals, published in 1671, makes mention, from his own knowledge, of two places in *Craven*, in the west-riding of *Yorkshire*, where formerly good silver ore (lead ore abounding in

* Sir J. Pettus, Essay on Metal. Works.

† Rym. Fœd. Tom. XX. 164.

‡ Some Account of Mines, p. 6.

in ſilver) had been gotten. One of the places was *Brunghill* moor in the pariſh of *Slaidburn*, the ore of which held about the value of ſixty-ſeven pounds of ſilver in a ton: the other was *Skelkorn* field within the townſhip of *Rimmington* in the pariſh of *Giſburn*; it had formerly belonged to one *Pudſey*, who is ſuppoſed to have coined the ſilver he got out of his mine, there being many ſhillings in that county which the common people called Pudſey's ſhillings*.

There is not at preſent any place in *Derbyſhire* where ſilver is extracted from lead. A work of this kind was eſtabliſhed a few years ago not far from *Matlock*, and the lead yielded fourteen ounces of ſilver from a ton; but the mine which afforded the

* Webſter's Metal. p. 21.

the ore was ſoon exhauſted, or became too difficult to be worked with profit. There is a lead mine in *Patterdale* near *Keſwick*, which yields between fifty and ſixty ounces of ſilver from a ton of the lead: the ore of this mine is reckoned to be poor in lead; and indeed it is very commonly obſerved, that the pooreſt lead ores yield the moſt ſilver, ſo that much ſilver is probably thrown away, for want of having the ores of the pooreſt ſort properly aſſayed.

The quantity of lead ſmelted annually in Derbyſhire, may be eſtimated at 7,500 tons upon an average; fifty years ago the average was, probably, 10,000 tons a year, but we put it high enough in ſuppoſing it, at preſent, to amount to 7,500 tons: I have never been able to get any proper

proper information, concerning the quantity of lead annually ſmelted in other parts of Great Britain, but for the illuſtration of the ſubject we are upon, let us ſuppoſe, that in the whole kingdom 30,000 tons of lead are annually ſmelted, and that at a medium each ton of lead would yield 12 ounces of ſilver; then would there be, if all the lead was refined, a ſaving of three ounces of ſilver from each ton of lead, or ninety thouſand ounces in the whole; our Engliſh workmen reckoning that nine ounces of ſilver are full adequate to the expence of refining a ton of lead, added to that of the lead which is loſt during the operation.

The general manner of extracting ſilver from lead is every where the ſame; it is very ſimple, depending upon

upon the different eſſential properties of the two metals.—It is an eſſential property of lead, when melted in the open air, to loſe its metallic appearance, and to burn away into a kind of earth.—It is an eſſential property of ſilver not to burn away, or to loſe its metallic appearance when expoſed to the action of the ſtrongeſt fires, in the open air. Hence, when a maſs of metal, conſiſting of lead and ſilver, is melted in the open air, the lead will be burned to aſhes, and the ſilver remaining unaltered, it is eaſy to underſtand how the ſilver may be extracted from the lead; for being heavier than the aſhes of the lead, and incapable of mixing with them (ſince no metal is miſcible with an earth), it will ſink to the bottom of the

the vessel in which the mass is melted. Iron, tin, and copper, resemble lead, in being convertible into a kind of ashes, when exposed to the action of air and fire, and gold resembles silver in not undergoing any change from such action; hence either gold or silver, or a mass consisting of both, may be purified from any or all of these metals by the mere operation of fusion; for these metals will rise to the top of the vessel, in which the fusion is made, in the form of an earth or dross, leaving the gold or silver pure at the bottom.

The ancients certainly knew that silver could be purified from the base metals by the force of fire.— *The house of Israel is to me become dross: all they are brass (copper), and tin,*

tin, and iron, and lead, in the midst of the furnace, they are even the dross of silver *. And as we read of silver being purified seven times in a furnace of earth †, it may, perhaps, be inferred, that the method of refining silver, which was then in use, consisted in reducing the base metals into earth, by a repetition of the process of fusion. This inference, it must be owned, is rendered doubtful by a passage in *Jeremiah*;—*the bellows are burned, the lead is consumed of the fire, the founder melteth in vain* ‡. —This passage is somewhat ambiguous, and interpreters translate the original Hebrew differently, but most of them collect from it, that the founder

* Ezek. xxii. 18. † Ps. xii. 6.
‡ Jerem. vi. 29.

founder added lead to the mixed maſs which he wanted to refine.

Lead, when reduced to an earth by being burned in the open air, may, in a ſtronger degree of heat, be converted into a yellowiſh glaſs *, which

* Other metallic ſubſtances yield coloured glaſſes, either when vitrified alone, or in conjunction with pure glaſs. In enamel and china painting, they prepare roſe red and purple colours from gold; ſcarlet reds from iron, or vitriols that partake of it; greens from copper; blues from cobalt; blacks from magneſia, zaffer, and ſcales of iron; yellows from ſilver antimony, Naples yellow, and crocus martis; white from tin. The ſame ſubſtance yields different colours, according to the degree of heat to which it is expoſed; thus, the green colour of common glaſs bottles, which proceeds from the iron contained in the ſand and vegetable aſhes from which the glaſs is made, is changed into a blue by a ſtronger degree of heat.

which has the property of greatly contributing to the eafy vitrification of all earthy fubftances; hence, when gold or filver are mixed with iron, copper, or tin, it is ufual to add to the mixed mafs a quantity of lead, in order to accelerate the purification; for the lead will be converted into glafs, and this glafs will vitrify all the extraneous fubftances with which the gold or filver are polluted, without exerting the leaft action upon the precious metals themfelves.

I do not know upon what grounds one of the moft diftinguifhed chemifts of the age has afferted, "that the refining of gold and filver merely by the action of the fire was the only method anciently known;" † and

† Chem. Dict. by M. M—— Refining.

and that the doing it by the addition of lead, is a difcovery with which the ancients were unacquainted. Not to infift upon what has been quoted from *Jeremiah*; in *Diodorus Siculus* there is a very minute defcription of the manner of working fome gold mines in the confines of *Egypt* and *Arabia*; this defcription was probably written on the fpot when he vifited that country, but the mode of operation feems to have been derived from a more early period; as the difcovery of the mines is attributed by him to fome of the moft ancient *Ægyptian* kings; amongft other particularities, he takes notice of their melting the mineral in conjunction with a little tin, fome fmall portion of falt, and a lump of *lead*.*

Strabo

* Diod. Sic. Lib. III. p. 183—189.

Strabo quotes *Polybius* as ſpeaking of a ſilver ore, which, after being five times waſhed, was melted with *lead*, and became pure ſilver. Unfortunately this part of the works of Polybius is loſt, or we might have had a more circumſtantial knowledge of the proceſſes by which the ancients extracted ſilver from its ores, as Strabo ſays, that he omitted Polybius's account of this matter, becauſe of its prolixity.* *Pliny* probably has an alluſion to the uſe of lead in refining ſilver, when he ſays, that a ſilver ore in the form of an earth could no be melted except in conjunction with lead or the ore of lead.† A more diligent ſearch into the writings of the ancients would, doubtleſs,

* Strab. Geo. Lib. II. p. 221.

† Plin. Hiſt. Nat. Lib. XXXIII. C. 6.

leſs, furniſh more authorities upon the point, but theſe may be ſufficient to induce us to believe, that they were not unacquainted with the uſe of lead in refining gold and ſilver.—But to return to the manner of extracting ſilver from lead.

The veſſel in which the workmen melt the maſs of ſilver and lead, is of a ſhallow form, that a large ſurface of the melted maſs may be expoſed to the air; it is made uſually of four meaſures of the aſhes of calcined bones, and of one meaſure of unwaſhed fern aſhes, and is called a *teſt*.* This veſſel is very porous, but

* Teſts are ſometimes made of clay and other materials, and metallurgic writers often order the wood aſhes to be waſhed, leſt the alkaline ſalts which they contain ſhould tend to vitrify the teſt; but a very good refiner

but not ſo much as to imbibe the metal, whilſt it continues in the form of a metal; but as the earth, into which the lead is ſoon reduced by the action of the fire, becomes melted, the teſt imbibes a portion of it in that liquid ſtate, the other portion is driven off (as cream is blown off from milk) from the ſurface of the melted maſs, by the blaſt of a bellows. The liquid, half vitrified, earth of lead, which is thus driven off, concretes into hard maſſes of a ſcaly texture, and is called in that ſtate *litharge*, or ſilver ſtone, from the manner of its being produced, or from an idle notion of its containing

finer at Holywell informed me, that he always uſed the aſhes without waſhing them, as the veſſel became thereby leſs apt to crumble into pieces.

taining much ſilver. The litharge which is firſt formed is whitiſh, that which experiences a greater degree of heat is red ; the colour of the litharge is alſo influenced by that of the other metals, which may chance to be mixed with the maſs of lead and ſilver. When the ſurface of the melted maſs becomes white, and throws up no more litharge, the operation is finiſhed; but as the remaining ſilver is not quite pure, ſince it contains a ſmall portion of lead, from which the degree of heat requiſite for melting the mixed maſs cannot readily free it, it is taken to a refining furnace, and rendered quite pure, at leaſt from lead, by *cupellation.* This proceſs conſiſts in melting the ſilver obtained from the firſt operation, in a veſſel made of the

ſame materials as the teſt, and which from its reſemblance to a wide-mouthed cup, has been called a *cupel.* The cupel being expoſed to a ſtronger heat than the teſt, the lead which had eſcaped the action of the fire on the teſt; is now driven out from the ſilver, and being converted into litharge, is abſorbed by the cupel; and by this means the ſilver is purified from every metal except gold; for it is not neceſſary, on this occaſion, to remark, that a minute portion of copper, when there happens to be any in a maſs of ſilver and lead, probably eſcapes the action of the fire in cupelling gold or ſilver.

There are ſeveral ſmelting houſes at *Holywell* in *Flintſhire*, where ſilver is extracted from lead; Mr. *Pennant** has

* Tour through Wales.

has given the following account of the quantity of ſilver extracted at one of the largeſt of theſe houſes in the courſe of ſix years.

	ounces.		ounces.
Year 1754	- 12160	Year 1774	- 5693
1755	- 1276	1775	- 6704
1756	- 7341	1776	- 4347

The ſilver obtained from lead at *Holywell*, is chiefly ſold to the manufacturers at *Birmingham* and *Sheffield*. Much ſilver is alſo extracted from lead in *Northumberland*.

At Holywell they uſually work off three tons of lead at one operation, the quantity of ſilver which they procure, is variable according to the richneſs of the lead; a few years ago they were refining lead from an ore found in the *Iſle of Man*, and it gave them about 60 ounces at every ope-

operation, or 20 ounces in a ton of the lead. The litharge ordinarily obtained from three tons of lead amounts to 58 hundred weight; this litharge may either be changed into red lead by calcination, or it may be reduced into lead again by being fluxed with charcoal, or any other matter containing the inflammable principle,* but when it is *reduced* they seldom obtain more than 52 hundred weight of lead,† so that by ex-

* Lead from litharge is, generally speaking, worth five shillings a ton more than ore lead, as the plumbers esteem it softer and fitter for making sheet lead; yet the litharge lead from the ore of the Isle of Man here mentioned, was found quite unfit for making sheet lead, on account, probably, of the ore having held other metals beside silver and lead.

† In the foreign works they estimate the loss of weight, which the litharge sustains in being

extracting the silver, there is a loss of eight hundred weight in three tons of lead. It has been said that the *Dutch* can extract the silver from three tons of lead, and not lose above six hundred weight * upon converting the litharge into lead, and that this superior skill, aided, probably, by their superior industry, enabled them to purchase our lead, and to extract the silver from such as could not be refined here with advantage: I have been informed, however, by an experienced refiner in Derbyshire, that he could extract the silver without losing quite so much as six hundred

being reduced into lead, at a sixth part of the weight of the litharge, or 9⅔ hundred weight from 58 hundred weight of litharge. Essais des Mines, Tom. II. p. 401.

* Webster's Metal. p. 233.

dred weight in three tons of lead; I make no queſtion that the loſs depends, in ſome meaſure, on the quality of the lead. It has been remarked before, that lead, which does not contain nine ounces of ſilver in a ton, is not thought worth the refining; the ſmalleſt quantity which can be extracted with profit, muſt depend much upon the price of lead, all expences attending the ſeveral proceſſes being the ſame. For eight hundred weight of lead, which may be aſſumed at a medium as the loſs ſuſtained during the operations of *refining* and *reducing*, is worth 6l. when lead is at 15l. a ton, and it is worth only 4l. 16s. when it is at 12l. a ton. The value of 27 ounces of ſilver, which we ſuppoſe to be the quantity ſeparable from three tons

of

of lead, is 7l. 10s. 9d. at 5s. 7d. an ounce; hence, the difference between the value of the silver obtained and that of the lead lost, would, when lead is at 15l. a ton, be 1l. 10s. 9d. and when lead is as low as 12l. a ton, it would amount to 2l. 14s. 9d. In the times of Sir *John Pettus*, the usual allowance for waste in refining and reducing of lead, was three hundred weight in a ton, or nine hundred weight in three tons, and the lead was valued at 12l. a ton,* so that lead has altered very little in its price in the course of above one hundred years.

Silver is here valued at 5s. 7d. an ounce; this requires some explanation. A pound of *standard* silver in England, consists of 11 ounces

* Fodinæ Reg. p. 10.

ounces and 2 pennyweights of *fine* ſilver, and of 18 pennyweights of copper; in other words, every maſs of *ſtandard* ſilver conſiſting of 40 parts by weight, is compoſed of 37 parts of *fine* ſilver, and of 3 parts of copper; the copper is called the *alloy*. All nations uſe ſome alloy both in their gold and ſilver; partly with a view of rendering theſe metals harder, and partly becauſe it would require much labour and expence to free them wholly from that ſmall portion of copper, which in their ordinary ſtate, as fluxed from their ores, they are generally found to contain. A pound of *ſtandard* ſilver is coined into 62 ſhillings, hence the *Mint* price of an ounce of *ſtandard* ſilver would be a twelfth part of 62 ſhillings, or 5s. 2d. From hence

it might be ſhewn, by the rule of proportion, that the *market* price of an ounce of *fine* ſilver, which contains no copper, will be 5s. 7d. at the leaſt. The market price of ſilver bullion does not wholly depend on the mint price, it can never be lower than that, but, from the operation of various cauſes, it may exceed it. †—*Standard* gold with us conſiſts of 11 parts of *fine* gold, and of 1 part of copper, or of a mixture of ſilver and copper; and a pound or 12 ounces of ſtandard gold, is coined into 44½ guineas; hence the price of an ounce of ſtandard gold is 3l. 17s. 10½d. and the price of an ounce of *fine* gold is 4l. 4s. 11½d. Foreign gold trinkets ſtain the hands more, and have a more coppery

† Eſſay on Money and Coins, p. 2. and 55.

pery look than English ones; and in fact they are made of gold which is alloyed with a much greater proportion of copper, than the standard gold of England; yet, when an enamel is to be fixed on gold, one of the most experienced of the foreign enamellers † recommends the use of gold, which has the same alloy as the English standard gold, or two parts alloy, and twenty-two parts of fine gold.

Copper communicates a smell both to gold and silver. The *Roman specula*, which they used as looking glasses, in *Pliny*'s time were commonly made of silver, but the silver was alloyed with much copper; for we find a cunning waiting maid in *Plautus* advising her mistress

† M. de Montamy, Traité des Couleurs.

treſs to wipe her fingers after having handled a ſpeculum, leſt her paramour, from the ſmell of her fingers, ſhould ſuſpect her of having received ſilver from ſome other lover.

Ut ſpeculum tenuiſti, metuo ne oleant argentum manus,
Ne uſque argentum te accepiſſe ſuſpicetur Philolacles.*

* Plaut. Moſt. Act. I.

ESSAY

ESSAY X.

OF RED AND WHITE LEAD.

IF the reader does not know what *minium* or *red lead* is, I would wiſh him to ſend for a few ounces of it to his painter or apothecary.— Suppoſing him to have a parcel of red lead before his eyes, the firſt thing which will ſtrike him is its vivid colour verging a little towards orange; if he crumbles it between his

his fingers, he will find it to be an almoſt impalpable powder; if he poizes it in his hand, he will perceive it to be much heavier than either brick duſt or red ochre, with which ſubſtances it is ſometimes adulterated; if he compares it with a piece of lead, he will be aſtoniſhed how it can be either produced from lead, or be capable of being, by a very ſlight operation, *reduced* into lead again.

It has been mentioned in the preceding Eſſay, that red lead is made from *litharge* at *Holywell*: this red lead, which is made from litharge, is not perhaps, in all its properties, of quite the ſame kind with that which is made directly from lead; at leaſt I have been informed, that the makers of flint glaſs, who uſe much red

lead

lead in the compoſition of that glaſs, are of opinion, that the litharge red lead does not flux ſo well as that which is made from the direct calcination of lead, as is practiſed in *Derbyſhire*. There are in that country nine red-lead mills or furnaces, all of which are much upon the ſame conſtruction.

The furnace is very like a baker's oven, its vaulted roof is not at a great diſtance from the bottom or floor, on each ſide of the furnace there are two party walls, riſing from the floor of the furnace, but not reaching to the roof; into the intervals, between theſe walls and the ſides of the furnace, the pit-coal is put, the flame of which being drawn over the party walls, and ſtriking upon the roof, is from thence reflected

down upon the lead, which is placed in a cavity at the bottom, by which means the lead is ſoon melted. The ſurface of melted lead, when expoſed to the open air, inſtantly becomes covered with a duſky pellicle; and this pellicle being removed, another is formed, and thus by removing the pellicle, as faſt as it forms, the greateſt part of the lead is changed into a yellowiſh green powder. This yellowiſh powder is then ground very fine in a mill, and being waſhed, in order to ſeparate it from ſuch parts of the lead as are ſtill in their metallic ſtate, it becomes of an uniform yellow colour, and, when it is dried to a proper conſiſtency, it is thrown back again into the furnace, and being conſtantly ſtirred, ſo that all its parts may be expoſed to the

action

action of the flame of the pit coal, in about 48 hours it becomes *red lead*, and is taken out for use.

The colour of the red lead admits some variety, which is occasioned by the different degrees of heat. If the heat is too small, instead of red it is yellow or orange coloured; if it is too great, the red colour is changed into a dirty white; between these two extremes it is subject to some diversity of shades of red, which cannot well be noticed or described, except by those who are engaged in the making of it.

It has been asserted, that the reverberation of the flame and smoke upon the surface of the lead, is not a necessary circumstance in giving it a red colour *; but that it will ac-

 quire

* Instit. de Chym. par M. Demachy, p. 521.

quire this colour by a long calcination without coming into contact with the flame. The truth of this assertion I think may be doubted. I have more than once calcined lead for above 60 hours, without suffering the flame of the fire to touch it during any part of the process, but by this method I could never obtain any thing better than a dirty red, resembling the red of brick dust, which is very different from the colour of red lead; and even this dirty red was changed into a yellow colour, by augmenting the degree of heat with which the lead had been calcined. The method of making red lead is very well understood in *England* and *Holland*, but not in *France*; and the French workmen are

of

of opinion that it cannot be made by the flame of wood fires*.

During the making of red lead, part of it is volatilized, there rises up from it a vapour, which attaches itself to the roof of the furnace, and forms solid lumps. These lumps are of a yellowish white colour mixed with pale green and some reddish streaks, wherein are frequently small red crystals, resembling such as may be artificially formed by subliming sulphur and arsenic together. The workmen call the whole of what is separated from the lead in the form of smoke, sulphur: when this sublimed matter is detached from the roof of the furnace, the red parts

* Mem. de l'Acad. des Scien. 1770.— Elemens de Mineral. par M. Sage, Vol. II. p. 248.

are converted by a ſubſequent proceſs, into red lead; and the yellow ones are ſent to the ſmelting furnaces, to be run down again into lead. The quantity of this ſublimate amounts to about five hundred weight in making one hundred tons of red lead. The proportion here aſſigned is not wholly to be relied on, ſince the ſmoke ariſing from the lead forms itſelf into larger maſſes, and in leſs time, when it is not conſtantly ſwept from the roof of the furnace than when it is; and the workmen endeavour to keep the roof as free from it as they can, becauſe a ſmall portion of it injures the colour of a large quantity of the red lead with which it happens to be mixed.

A ton or twenty hundred weight of

of lead generally gives twenty-two hundred weight of red lead, notwithstanding the loss of substance which the lead evidently sustains from the copious smoke which arises from it during the operation. Some authors tell us, that the increase in the weight of the red lead is double what I have here mentioned: thus, *Orschall* speaking of the red lead made at *Nuremberg*, assures us, that 100 pounds of lead yield 120 pounds, and sometimes even more, of red lead *. It is not impossible that, according to the different manners of conducting the process, there may be a difference in the quantity of weight which the red lead acquires: I had my information from some of the most

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* Orsch. Metal. French Transl. p. 100.—— M. Sage's Miner. Vol. II. p. 384.

experienced makers of red lead in Derbyſhire. There have been great diſputes amongſt philoſophers, to what principle this increaſe of weight ſhould be aſcribed; ſome have attributed it to what they call the matter of fire; others are upon good grounds convinced, that it is owing to the abſorption of the air itſelf, or of ſome of the principles of which the air conſiſts. This hypotheſis concerning the fixation of air during the calcination of metals, is ſaid to have been firſt advanced by *John Rey*, a French phyſician, in 1630; Dr. *Hales* was partly of the ſame opinion*; and Dr. *Pemberton* very expreſsly affirms, that calcined metals receive their increaſe of weight from the air, which, " by acting on the inflamma-

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* Veget. Stat.

ble ſubſtance, either in metals or other bodies, expels it from them, and unites itſelf (in part at leaſt) to the remains of the body*." The ingenious labours of Dr. *Prieſtley* and of M. *Lavoiſier* have confirmed the conjectures and experiments of former philoſophers, for they have clearly proved two points — firſt, that a large portion of air may be *ſeparated* from red lead, by *reducing* it to the ſtate of a metal;— and ſecondly, that a large portion of air is *abſorbed* by *lead* during the calcination, by which it is reduced to the ſtate of red lead†.

During the calcination of lead, it is certain, from what has been ſaid, that

* Pember. Chem. p. 245.

† Prieſtley's Exper. and Lavoiſier's Eſſays, tranſlated by Henry.

that much of its ſubſtance is diſperſed into the air; this ſubſtance may indeed be ſeen aſcending as a ſmoke from the ſurface of the lead, if the heat be ſo great as to make it boil; and in a leſs degree of heat, the vapour which aſcends from it may be rendered viſible, by holding over it a wet iron ladle to condenſe it. But at the ſame time that the lead loſes conſiderably of its weight by the volatilization of part of its ſubſtance, it receives ſuch an acceſſion of new matter from the air, as renders the weight of the part which remains, much greater than that of the whole lead which was expoſed to calcination. This acceſſion of aërial matter may be driven off from red lead, by reſtoring to it the inflammable principle which was conſumed during

the calcination; but after this extraneous matter is driven off by reducing the lead, we ought not to expect that the lead, which is thus brought back to its former ſtate, ſhould weigh as much as it did before it was calcined; becauſe that part of it which was volatilized and diſperſed into the air cannot be recovered. And in fact, it was obſerved in the laſt Eſſay, that three tons of lead, when converted by calcination into litharge, had loſt two hundred weight; this quantity, and, probably, much more than this, had been volatilized and loſt, for the remaining fifty-eight hundred weight conſiſted partly of the earth of lead, and partly of the air which had been fixed in it during the calcination; and hence, when it was reduced, it did not give

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above fifty-two hundred weight. In calcining then, and reducing sixty hundred weight of lead, there is a loss of eight hundred weight: a great part of this loss is rightly referred to the volatilization of the lead, but a part also may justly enough be referred to the scoria which remains after the reduction of the litharge into lead, that operation being seldom performed so accurately as not to leave some part of the litharge unreduced. I have here spoken of the loss of weight sustained during the reduction of litharge, as if it was the same as that which red lead sustains; there probably may be some difference between them, but the general inference is the same; and I have been informed moreover, that there is neither increase nor de-

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creaſe in weight in converting litharge into red lead*.

In making red lead in Derbyſhire, the workmen mix one hundred weight of *ſlag* lead with about eighteen hundred weight of *ore* lead; and they are perſuaded that this ſlag lead has a great effect, in accelerating the converſion of the other lead into an earth. *Tin*, when mixed with lead, very much promotes its calcination; and the ſlag lead has this pro-

* This obſervation does not accord with that of the author of the Familiar Diſcourſe concerning Mines, p. 34.—— "20 hundred weight of this litharge will produce 22 hundred weight of red lead." Another author informs us that 20 pounds of lead will, by a long calcination, give 25 pounds of aſhes, and that theſe 25 pounds of aſhes will, when reduced, give 19 pounds of lead. Lemery Cours de Chym. p. 145.

property in common with a mixture of tin and lead, that it does not, when melted, exhibit any colours on its surface: may not its properties, by which it is diſtinguiſhable from ore lead, ariſe from its containing zinc or tin? We are too apt, I think, to look upon the ores of lead as containing only one metal; ſince we are certain that they all contain two, namely, lead and ſilver; and it may be, that they contain other metallic ſubſtances, particularly zinc and tin.

In converting a ton of lead into red lead, the workmen obſerve, that towards the end of the operation, a few pounds of lead are always found to remain, which cannot be changed into red lead, with the ſame facility with which ordinary lead is changed. When I was firſt informed

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of this circumſtance, I conſidered it in the following manner.—Derbyſhire lead, though it does not contain ſilver enough to render the extraction of it profitable, yet it generally contains five or ſix ounces in a ton: ſilver is not capable of being converted into an earth by the action of air and fire, when therefore a ton of lead is converted, as to its greateſt part, into red lead, why may not the ſix ounces of ſilver contained in that lead be left unaltered? and may not the ſuperior difficulty of reducing the laſt portion of the lead into red lead, proceed from hence, that it is much more impregnated with ſilver, than ordinary lead is? Under the influence of this conjecture, I procured from Derbyſhire, ſome of the lead which remained un-

uncalcined in the making of red lead, and I aſſayed it for ſilver, but it did not contain more ſilver than many ſpecimens of ore lead contained.

It has been remarked more than once that red lead may be *reduced* into lead, by being melted with roſin, tallow, charcoal, or any ſubſtance containing the inflammable principle. The proof of this is very eaſy; a few grains of red lead being ſcattered on a piece of red hot-charcoal, will be changed into globules of lead; or if the reader burns a common red wafer in the flame of a candle, holding a piece of white paper under it, he will ſee many red-hot globules falling upon the paper, and theſe globules he will find to be lead: this lead proceeds from the

the red lead with which ordinary wafers are coloured, being *reduced* into the ſtate of a metal, by uniting itſelf with the inflammable principle. The beſt wafers are coloured with vermilion—powdered *cinnabar**.

Having been diſappointed in the expectation of finding a large proportion of ſilver, in the ſmall reſidue of lead remaining after the converſion of ordinary lead into red lead; and being unwilling to give up the notion, I was deſirous of convincing myſelf that I had not been guilty of any miſtake in the aſſay that I had made, by trying whether red lead itſelf did not contain ſilver; for if red lead contained ſilver, I ſaw no reaſon

to

* Cinnabar is an ore of quickſilver; it is compoſed of quickſilver and ſulphur; generally of 7 parts of quickſilver to 1 of ſulphur.

to be surprised at the residue, before mentioned, not containing more than I found it to do. I therefore reduced a quantity of red lead into the state of a metal, by melting it with rosin; this reduced lead was carefully assayed more than once, and it always afforded a portion of silver. Hence we may conclude, that the silver contained in lead, though it be not subject to calcination during the process of making red lead, is nevertheless mixed with the calcined lead in such a comminuted state, as to escape our senses; the silver, probably, is still in the form of silver, but its particles are so indefinitely fine, that they cannot be distinguished in the mass of red lead, which contains them.

The method of making flag lead has

has been defcribed before; I affayed this kind of lead feveral times, and I fometimes obtained from it a globule of filver, at other times there was no appearance of filver. This difference in the refult of the affays is not to be attributed to any difference in the quality of the flag lead which was affayed, for all the pieces which I tried were cut from the fame lump; but to the different degrees of heat ufed in the operation; when the fire was too ftrong, the filver, I conceive, was *volatilized.* Silver, I know, is looked upon as a *fixed* metal, and not capable of being volatilized; and the lofs of filver, when the fire is too ftrong, has been attributed to its not being volatilized, but abforbed by the *cupel*: I have no objection to this account:

but that the volatilization of ſilver on the cupel is no unwarranted conjecture, appears from hence, that in the laſt proceſs of refining lead for ſilver at Holywell, ſo much of the ſilver is carried into the chimney of the furnace, that they have procured a ſilver cup from melting the ſweepings.

A great quantity of lead is annually imported in the tea boxes from China; a Congo box contains about 10 pounds, and an Hyſon box about 4 pounds of lead; I have frequently aſſayed this lead, and always found that it contained ſilver, but not in quantity ſufficient to quit the expence of extracting it.

Pure lead is heavier than pure ſilver, and the purer the lead the greater is its weight; I calculated the weight

weight of a cubic foot of five different sorts of lead:

	Weight of a cubic foot of Avoir. oz.
Lead from the reduction of red lead	11460
Lead uncalcined in making red lead -	11331
Lead smelted from an ore - - - -	11262
Lead from the slag of a cupola furn.	11212
Lead from a tea box - - - - - -	11176

The experiments from which I formed this table were repeated at different times, and the mean of several trials in the respective sorts is expressed. A cubic foot of fine silver weighs 11091 ounces *.

The following assays of the several leads here mentioned, were made by an experienced assayer in London; they are very little different from those

* Cotes.

those which I myself had made, but I was desirous that the reader might rely upon the authority of a person versed in the particular business of assaying, rather than upon mine.

Fine silver in a pound of	Grains
Lead from the reduction of red lead -	$1\frac{1}{2}$
Lead uncalcined in making red lead	$1\frac{1}{2}$
Lead smelted from an ore - - -	$1\frac{3}{4}$
Lead from the slag of a cupola furn. -	$1\frac{3}{4}$
Lead from a tea box - - - - - -	$1\frac{3}{4}$

From comparing the two tables together, we see that the heaviest lead contains the least silver. I do not think, that persons interested in knowing the quantity of silver contained in any particular specimen of lead, should rest satisfied with assaying so small a portion as a pound, especially if no notice is taken of

any weight less than one fourth of a grain.

White lead, or *ceruse*, is lead corroded by vinegar. Thin plates of lead are rolled up in a spiral form, and placed in earthen pots containing vinegar; these pots being ranged on proper stages, and their mouths being covered in such a manner as to permit the vapour of the vinegar to escape, and at the same time to prevent any impurity from falling into them, a quantity of horse-dung is thrown in amongst them; by the heat of which, as it grows putrid, the vinegar is raised in vapour, and this vapour attaching itself to both sides of every spiral of the lead, which is so placed as not to touch the vinegar, it corrodes the lead into white scales, which being beat off from

from the plates, washed and ground in a mill, constitute the white lead of the shops, excepting that this is generally, even before it gets into the hands of the painters, adulterated with chalk. Ceruse was formerly made by the vapour of putrid urine instead of vinegar. The time when this preparation of lead was first discovered, is wholly uncertain; *Dioscorides* speaks of its being made in great perfection at *Rhodes*, *Corinth*, and *Lacedemon*, and of an inferior sort of it at *Puteoli* *; and *Pliny* describes two ways of conducting the operation, both of which are now in use†.

The *Roman ladies* were well acquainted with the use of ceruse as a cosmetic: *Plautus* introduces a waiting

* Diosc. Lib. V. C. 103.
† Lib. XXXIV. S. 54.

ing woman refuſing to give her miſtreſs either *ceruſe* or *rouge*, becauſe, forſooth, in the true ſpirit of a flattering Abigail, ſhe thought her quite handſome enough without them*. I ſuppoſe the Chriſtian ladies in the days of *St. Jerome*, were given to this pagan cuſtom, for the venerable father inveighs very forcibly againſt the

* —— non do ſcita es tu quidem,
Nova pictura interpolare vis opus lepidiſſimum,
Non iſtanc ætatem oportet pigmentum ullum attingere,
Neque ceruſam, neque melinum, neque aliam ullam offuciam.
Plaut. Moſt. Act. I.

Quid faciat in facie Chriſtianæ purpuriſſus et ceruſa, quorum alterum ruborem genarum, labiorumque mentitur, alterum candorem oris et colli, ignis juvenum, fomenta libidinum, impudicæ mentis indicia. Hieron. ad Furium.

the uſe of *rouge* for the lips and cheeks, and of *ceruſe* for the face and neck, as incentives to luſt, and indications of unchaſte deſires. Without preſuming to explore the *arcana* of a lady's toilet, or to reveal the arts by which my fair countrywomen endeavour to improve charms naturally irreſiſtible, I would add to the admonition of St. Jerome, a caution more likely, in theſe degenerate times, to be attended to — the certain ruin of the complexion, to ſay nothing of more ſerious maladies, which muſt ever attend the conſtant application of this drug. Nor is the *magiſtery* of *biſmuth* or *Spaniſh white*, as it is called, much leſs pernicious than ceruſe, notwithſtanding its being in ſuch repute in London, that the chemiſts can hardly

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prepare it faſt enough to ſupply the demand for it*. But if, as is moſt probable, they will neglect this caution, I warn them, however, to forbear the uſe of ſuch waſhes at Harrowgate, Moffat, and other places of the ſame kind, leſt they ſhould be in the ſtate of the unlucky fair one, whoſe face, neck, and arms were ſuddenly deſpoiled of all their beauties, and changed quite black by a ſulphureous water. Indeed, all phlogiſtic vapours, and even the ſun itſelf, tends to give both the magiſtery of biſmuth, and ceruſe, a yellow colour: this obſervation may explain a line

* The magiſtery of biſmuth is made by diſſolving that ſemimetal in aqua fortis, and precipitating the diſſolved biſmuth from the acid, by water.

a line in *Martial*, where a *cerused* lady is said to fear the sun*.

Other fluids, besides the vapour of vinegar, corrode lead into a kind of ceruse. When plumbers strip the roofs of churches, or other buildings covered with lead, which has lain undisturbed for many years, they usually find that side of the lead which is contiguous to the boards, covered with a white pellicle, as thick sometimes as an half crown; this pellicle is corroded lead, and is as useful for painting, and other purposes, as the best white lead. The lead on the south side of any building is found to abound most with this

* —cretata timet Fabulla nimbum,
Cerussata timet Sabella solem.
Mar. Ep. Lib. II. E. XLI.

this white cruſt; that on the north ſide having very little, or none at all of it. It is believed alſo, that lead which lies on deal boards, is not ſo apt to be covered with this white incruſtation, as that which lies upon oak: if there be any truth in this obſervation, it may, perhaps, be explained from hence, that oak contains a much ſtronger acid than deal, and this ſtrong acid being diſtilled, as it were, by the heat of the ſun in ſummer, attaches itſelf to the lead, and corrodes it: or this corroſion may be the effect of the ſun and air, which, by their conſtant action, calcine or corrode the lead; and this calcined lead not being waſhed off by the rain, may, in the courſe of a great many years, form the cruſt here ſpoken of. It might be worth

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while, in a philoſophical view, to examine more minutely than has been done, the difference between old lead which has loſt ſome of its parts by long expoſure to the air, and new lead. The plumbers have aſſured me, that if a pig of old lead, and an equal pig of new lead, be put together into the ſame iron pot, and expoſed to the ſame degree of heat, the new lead will be melted much ſooner than the old lead. Another difference betwixt them, reſpects the quickneſs with which they may be reduced to a *calx*, the new lead being obſerved to calcine much faſter than the old.

Neither ceruſe, nor litharge, nor minium, have any taſte; but any of theſe ſubſtances being boiled in diſtilled vinegar, which has an acid

taſte,

taſte, will be diſſolved in it; and the ſolution being cryſtallized will give one of the ſweeteſt ſubſtances in nature, called *Saccharum Saturni*, or ſugar of lead. It is this property which lead has of acquiring a ſweet taſte by ſolution in an acid, that has rendered it ſo ſerviceable to thoſe wine merchants who, reſpecting their own profit more than the lives of their cuſtomers, have not ſcrupled to attempt recovering wines, which had turned ſour, by putting into them large quantities of ceruſe or litharge. I believe this adulteration is puniſhed with death in ſome parts of *Germany*; and it is to be wiſhed that it met with that puniſhment every where. In 1750, the *farmers general* in *France* being aſtoniſhed at the great quantities *de vin gaté* which

were brought into *Paris*, in order to be made into vinegar, redoubled their researches to find out the cause of the great increase in that article; for near thirty thousand hogsheads had been annually brought in for a few years preceding the year 1750, whereas the quantity annually brought in forty years before, did not exceed 1200 hogsheads. They discovered, that several wine merchants, assuming the name of vinegar merchants, bought these four wines (which were still rendered more sour by the custom of pouring into each hogshead six pints of vinegar before it was sold), and afterwards, by means of litharge, rendered them potable, and sold them as genuine wines *.

Our

* Exam. Chy. de Differ. Subs. par. M. Sage, p. 157.

Our Engliſh vintners, there is reaſon to fear, are not leſs ſcrupulous in the uſe of this poiſon than the French wine merchants; for it not only corrects the acidity of ſour wines, but it gives a richneſs to meagre ones, and by this property the temptation to uſe it is much increaſed.

The reader may ſoon furniſh himſelf with the means of detecting lead when diſſolved in wine. Let him boil together in a pint of water, an ounce of quicklime, and half an ounce of flour of brimſtone, and when the liquor, which will be of a yellow colour, is cold, let him pour it into a bottle, and corking it up, reſerve it for uſe. A few drops of this liquor being let fall into a glaſs of wine or cider containing lead,

will change the whole into a colour more or less brown, according to the quantity of lead which it contains; if the wine be wholly free from lead, it will be rendered turbid by the liquor, but the colour will be rather a dirty white than a blackish brown. *Van Helmont* * was of opinion, that *Paracelsus* made no vain boast, in saying that he could cure two hundred diseases by preparations of lead; but he does not tell us of the many hundred persons he, probably, sent to their graves by his attempt. But it is beyond my ability, and falls not within my design, to discuss either the salubrious or poisonous qualities of lead; especially as the labours

* Adeo ut non frustra Paracelsus glorietur solo plumbo forte ducentas morborum classes superare posse. Helm. Op. p. 561.

labours of Sir G. *Baker** and Dr. *Percival*† have ſo fully illuſtrated that ſubject.

Having accidentally heard, during the printing of this volume, that Dr. *Prieſtley* had diſcovered a method of reducing red lead to its metallic form, by melting it, in contact with inflammable air, by means of a burning glaſs, I was very deſirous of having ſo remarkable a fact confirmed by other experiments. But being prevented by a bad ſtate of health from venturing into an elaboratory myſelf, I communicated my wiſhes and ideas to an ingenious gentleman of this univerſity‡, who has for ſome years been cultivating chemiſtry with

a pro-

* Med. Eſſ. † Eſſ. on the Poiſon of Lead.

‡ Rev. Mr. Milner, A. M. Fellow of Queen's College.

a proper degree of enthusiasm, and he has succeeded in reducing red lead by means of inflammable air in the following manner. To one end of a glass tube, into the middle of which some red lead had been put, an empty bladder was tied; to the other end a bladder full of inflammable air, obtained from a solution of iron in the acid of vitriol, was fastened very close: that part of the tube, in which the red lead was principally lodged, being heated almost red hot, by being held over a small crucible full of burning charcoal, the inflammable air was pressed out of the bladder; at its first passage through the tube the red lead became brown, as if it had been mixed with some *oleaginous* particles; and by pressing the bladders alternately for a short

a short space of time, the red lead was reduced into small globules of lead; the quantity of inflammable air was sensibly diminished, a part of it having been absorbed by the red lead when it became a metal.

Occasion was taken in another place to remark, the inflammable air, as a constituent part of combustible bodies, bore a great resemblance to phlogiston*, and a doubt also has been expressed, whether the phlogiston of metallic substances be not an elastic inflammable fluid; this experiment, in which lead is reduced by absorbing inflammable air, tends very much to strengthen that hypothesis, and I doubt not we shall see reason to admit it without hesitation, when the subject has been more investigated;

* Vol. II. p. 33.

investigated; at present I do not know whether it has been proved that the *whole* of any definite quantity of inflammable air can be absorbed by a metallic earth, nor, if it cannot, what the nature of the remainder is: but the removal of these, and other doubts, will be best accomplished by the ability of him, to whom we owe the first suggestion of the phlogiston of metallic substances being an inflammable air.

END OF VOL. III.